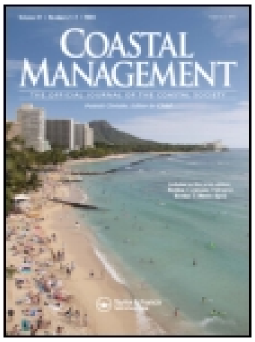


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# Spatially Prioritizing Seafloor Mapping for Coastal and Marine Planning

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# Spatially Prioritizing Seafloor Mapping for Coastal and Marine Planning

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*Coastal and marine areas provide vital services to support the economic, cultural, recreational, and ecological needs of human communities, but sustaining these benefits necessitates a balance between growing and often competing uses and activities. Minimizing coastal zone conflict and reducing human-induced impacts to ecological resources requires access to consistent spatial information on the distribution and condition of marine resources. Seafloor mapping provides a detailed and reliable spatial template on the structure of the seafloor that has become a core data need for many resource management strategies. The absence of detailed maps of the seafloor hinders the effectiveness of priority setting in marine policy, regulatory processes, and marine stewardship. For large management areas, the relatively high cost of seafloor mapping and limited management budgets requires careful spatial prioritization. In order to address this problem, a consensus based approach, aided by decision-support tools, and participatory geographic information systems (GIS), was implemented in Long Island Sound to spatially prioritize locations, define additional data collection efforts needed, and identify products needed to inform decision-making. The methodology developed has utility for other states and regions in need of spatially prioritizing activities for coastal planning, and organizations charged with providing geospatial services to communities with broad informational needs.*

**Keywords** Long Island Sound, mapping, prioritization, seafloor, spatial

## Introduction

Long Island Sound (LIS), located between Connecticut and the north shore of Long Island, New York, is the drainage basin for New York City and much of New England, a region that is home to nearly nine million people. Designated an Estuary of National Significance by Congress in 1987, LIS is regularly used by maritime shipping, recreational boaters, commercial and recreational fishermen, bathers, and nature lovers. Sustaining its coastal resources necessitates striking a balance between growing and often competing uses. In turn, this requires the availability of informational products to help inform maritime decision-making.

Coastal managers have long acknowledged the importance of seafloor mapping information to inform a wide range of coastal planning needs. Seafloor mapping data

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provides information for biological assessment (composition, extent, and condition of seafloor habitats), ecological linkages (fish and marine mammal distributions associated with topographic and habitat variability), geological characterizations (surficial sediment composition, geologic hazards, and morphology), and maritime archeology (shipwrecks and paleo-landforms). In addition, these data provide economic value by aiding maritime navigation and commerce, which requires accurate charting to support the safe and efficient movement of ships and goods.

Unfortunately, a lack of substantial scientific information on seafloor habitats in LIS, as reported by a Connecticut Task Force, has hampered the ability to properly respond to and address topics, such as in-water utility infrastructure (Task Force on Long Island Sound 2003). Subsequent efforts identified similar data gaps and deficiencies pertaining to benthic species and habitat identification, the availability of informative mapping products, and the identification of ocean management needs (Connecticut Energy Advisory Board 2004, CTDEP 2007). However, a settlement agreement reached in 2004 to resolve noncompliance with two LIS-crossing electric cable projects provided an opportunity to address these informational gaps in LIS. Funds in excess of $7M are being specifically directed to conduct a comprehensive seafloor mapping effort.

A consortium of federal and state agencies (Connecticut Department of Energy and Environmental Protection, the U.S. Environmental Protection Agency, the New York Department of Environmental Conservation, and the Connecticut and New York Sea Grant programs) were charged with directing the funds toward developing improved benthic data products for LIS. While the settlement fund represents a substantial amount to support this effort, it was determined that it would still be insufficient to effectively map and provide a full suite of data products needed to complete the entire Sound. Consequently, an approach using decision-support tools and participatory geographic information system (PGIS) was devised to identify regions of importance to maximize the use and effectiveness of available funding. PGIS is an approach that promotes the interaction and engagement of stakeholders through the use of spatial information to address decision-making processes about specific landscapes. The process implemented for LIS achieved the identification of priority mapping areas by incorporating input from a range of stakeholder groups. The priority focus areas identified represent the convergence of several factors, including ecological value, multiple uses, regulatory issues, resource management, and potential for further development. The spatial prioritization process developed, vetted, and adopted in LIS is described herein (Figure 1). When complete, the data will present the most comprehensive picture of the Sound, improve understanding of the area's underwater environment, and provide mapping tools critical to ocean and environmental planning (Battista and O'Brien 2012).

## The Practice of Spatial Prioritization

### *Understanding the Challenges*

Seafloor mapping can be a costly undertaking due to the combination of components needed to collect and process data, including ships, vessels, aircraft, or satellite platforms; sophisticated remote sensing sensors; high-end software; and technically experienced personnel. In addition to these direct costs, there are several variable factors determined by project-specific requirements that may also influence cost. These include the remoteness of the project area, depth of water, resolution of data needed, types of features needed to be mapped (e.g., number of habitat classes, spatial scale of habitat classes), environmental

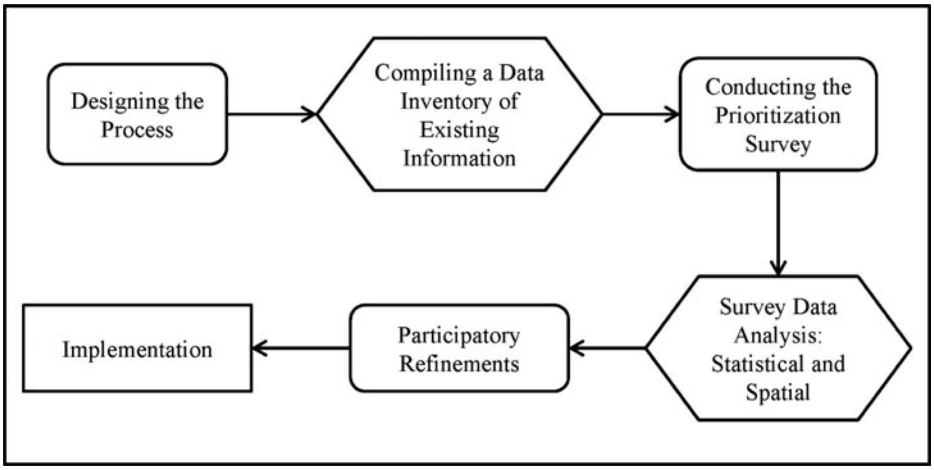



**Figure 1.** Spatial prioritization process.

conditions of the collection area (e.g., sea state, water clarity, cloud cover, hazards to navigation), survey size, and data certainty. The combination of these latter factors can escalate the cost of mapping shallow (0–150 m) coastal regions an order of magnitude higher than that of deep (>150 m) water areas (Todd et al. 2003). Conducting seafloor mapping in shallow water environments is more costly than deeper waters, yet shallow water coastal seafloors are also regions most heavily influenced by human use, including physical modification. Additionally, many locales lack access to the collection platforms, sensor technologies, and skilled remote sensing scientists to acquire the information needed. However, if conducted prudently and strategically, the investment in seafloor mapping will provide valuable return benefits, by promoting the availability of more complete information to aide in better planning and management of coastal resources.

### *Designing the Process*

Defining the parameters for a comprehensive seafloor mapping effort within a region is challenging. Achieving consensus among a broad range of downstream users regarding the application of seafloor mapping to explicit management challenges, identifying the types of products needed, and delineating locational priorities is inherently difficult. Additionally, the investment in seafloor mapping must also strategically consider, *a priori*, the multitude of applications these data will have in addressing a range of coastal marine challenges, including regulatory and permit consideration, living marine resource management, coastal development, coastal risk assessment, coastal change analysis, and anthropogenic impacts. A process to define these aspects must embrace conditions that encourage and ensure the maximum use and reuse of the data, and that simultaneously support multiple applications. Many seafloor mapping projects have the benefit of being narrowly focused in their application, such as hydrographic charting, shoreline change detection, and disposal site monitoring, which can greatly facilitate the planning aspects. However, planning projects where seafloor mapping data will be used to address a broad range of coastal and marine spatial planning (CMSP) applications can greatly complicate project planning. Success in LIS seafloor mapping involved inclusion of a wide range of collaborators across state, federal, academic, and nongovernmental organizations (NGOs) for cost-sharing and the identification of needs, applications and priorities.

### *Compiling a Data Inventory of Existing Information*

Existing geospatial data for LIS were compiled into a web-based data viewer to provide users access to a map-based inventory of currently available information. In this way, users could readily visualize the type, extent, and vintage (where available) of relevant seafloor mapping and biological resource information within LIS (Figure 2). Data mining was conducted for two months to identify and assimilate data from disparate sources (e.g., federal and state agencies, academic) into a centralized geodatabase. Evaluating the utility and quality of existing data was an important facet of the data aggregation effort. For instance, while it was identified that several acoustic surveys had been previously conducted in priority areas, these data were determined to be too antiquated or incomplete to resolve seafloor habitat features in sufficient detail to support their reuse in developing the final products.

After the data were compiled and standardized in the geodatabase, they were organized into six thematic groups: Marine Infrastructure, Critical Habitat, Sediment Sample Locations, Managed Areas, Survey Extents, Interpreted Geologic Surfaces, and Hydrography. These groupings were used to present the collected geospatial information in categories that were common and familiar to the expected end users. The geodatabase was then uploaded into a customized Web-based data viewer developed for the LIS project (http://maps.coastalscience.noaa.gov/dataviewer/dataviewer.html?id=LIS). ArcGIS API for Java Script was chosen to develop a data viewer as it provided core functionality (e.g., basemaps, panning, zooming, legend display, and polygon attribute querying), while providing a customizable, robust means to dynamically display diverse thematic data types.

In addition to the resource data included in the viewer, a grid framework was included to provide the spatial organizing unit for the subsequent prioritization survey to be conducted by participants (Figure 2, grid). The grid was comprised of 308 ($4 \times 4$ km) cells covering the full extent of the project area, and cells were labeled with a unique alpha-numeric code (A through U north to south and 1 through 46 west to east). The 16 $km^2$ cell size was chosen as a suitable compromise between cells being too coarse scale and not reflecting the important spatial geography of the region (fewer number of cells), and cells being too fine scale requiring considerable detailed input and interpretation by participants.

### *Conducting a Prioritization Survey*

The LIS data viewer was used to implement the second phase of the process—a prioritization survey. The objective of the prioritization survey was to solicit information from regional stakeholders to determine the location, type, and application of future seafloor mapping efforts. This concept borrows from a similar effort employed by the state of California (Kvitek and Bretz 2006), but was modified to capture greater detail of stakeholder input. For instance, particular attention was focused on designing a survey to capture the needs of a given location that could subsequently be used to define future data collection requirements and product types that are better able to address those needs. Here, the needs are governed by a combination of defined categories, including: Management Issues, Ranking Criteria (that modify or describe the Issue further), and Priority. Table 1 provides a list and definitions.

Key organizational stakeholders (groups) were identified to participate in the prioritization survey and asked to select one individual (i.e., participant) to coordinate and consolidate the group's collective responses into a coherent vision. In this way, submis-

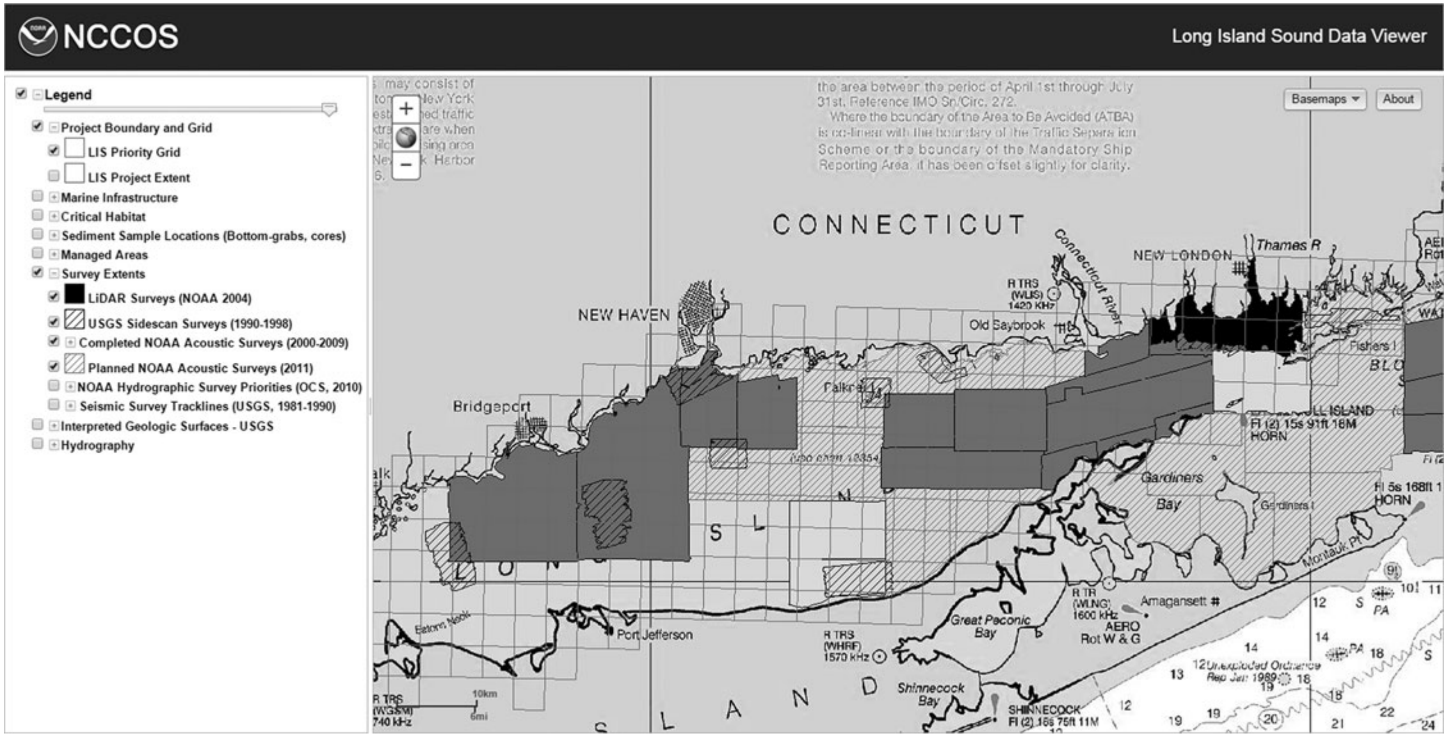



**Figure 2.** LIS spatial prioritization data viewer.

**Table 1**
Spatial prioritization form field definitions

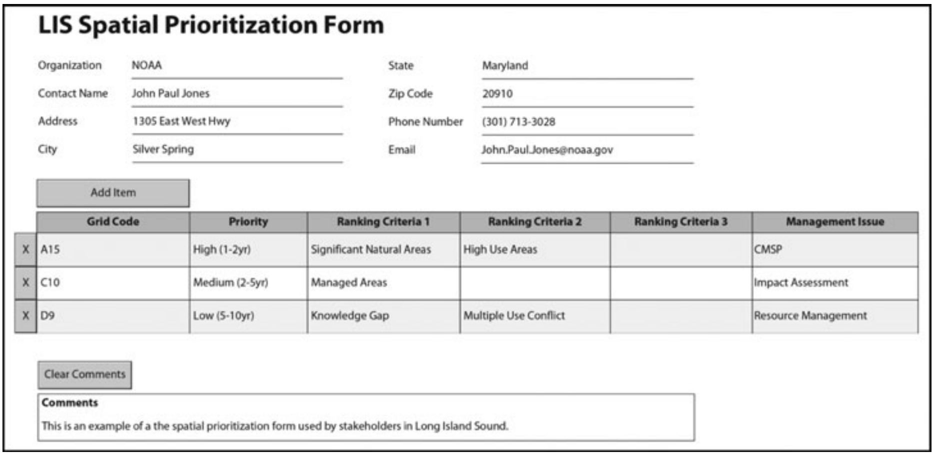
**Grid Code:** Alphanumeric Code for each of the 308 grid cells. Letters represent rows (A to U) and Numbers represent columns (1-46)

**Priority:** Select 1 of the 3 options. (Temporal aspect is based on anticipated start of data collection and/or analysis, not when products are produced.)
- High (1-2 yrs)
- Medium (2-5 yrs)
- Low (5-10 yrs)

**Ranking Criteria**: Select up to 3 options to rank the grid in descending order (1 being most important, 2 & 3 being successively less important.)
- Multiple Use Conflict - An area with known multiple non-authoritated competing uses (e.g., commercial fishing and recreational boating).
- Managed Areas - special use, managed resource harvest areas, or other designated State/Federal/Local managed areas (e.g., shellfish beds, dredge disposal sites).
- Significant Natural Areas - areas known to be of unique or important natural value, but not having any official or political designation (e.g., eelgrass beds, etc).
- High Use Areas - (e.g., ship traffic, fishing, commercial economic development zones).
- Existing Infrastructure - (e.g., cable, pipeline, etc).
- Potential Infrastructure - looking forward and considering the capacity of the area, is likely that it could be targeted for future infrastructure projects (e.g., cable, pipeline, wind/wave turbines, tidal energy devices, etc).
- Knowledge Gap - areas where there is no/limited/dated information.
- Other Conflict - areas where another conflict may occur but not captured by other categories (e.g., military exclusion zone, cultural resources, shipping channels).
- Other General - brief description of another criterion that captures an activity or theme not included above.

**Management Issue:** Select the overarching management issue driving the "Priority" designation. While there can be multiple concerns, please select the single most critical issue.
- Regulatory - information needed to inform permitting or regulatory assessments.
- Impact Assessment - data need to inform a non-regulatory impact assessment.
- Resource Management - data needed to inform resource management decisions, including harvested species as well as protected species (e.g., fisheries, shellfisheries, aquaculture, SAV, etc.).
- Monitoring/Research Design - data needed to inform the design of monitoring strategies or research programs.
- Evaluate Management Success - data need to inform or assess management decisions.
- CMSP - data needed to inform Coastal Marine Spatial Planning processes.
- Other - brief description on other management issue not included above.

sions could be considered more representative of organizational needs rather than reflecting personal biases or decisions made by individuals. Eleven groups (four state agencies, two academic institutions, one NGO, and three Federal agencies) submitted responses. Data on the number of people engaged by each group was not collected. Information was captured using a fillable Adobe Acrobat form (Figure 3) in conjunction with use of the data portal.



**LIS Spatial Prioritization Form**

Organization NOAA
Contact Name John Paul Jones
Address 1305 East West Hwy
City Silver Spring
State Maryland
Zip Code 20910
Phone Number (301) 713-3028
Email John.Paul.Jones@noaa.gov

Add Item

| | Grid Code | Priority | Ranking Criteria 1 | Ranking Criteria 2 | Ranking Criteria 3 | Management Issue |
|---|---|---|---|---|---|---|
| X | A15 | High (1-2yr) | Significant Natural Areas | High Use Areas | | CMSP |
| X | C10 | Medium (2-5yr) | Managed Areas | | | Impact Assessment |
| X | D9 | Low (5-10yr) | Knowledge Gap | Multiple Use Conflict | | Resource Management |

Clear Comments

**Comments**
This is an example of a the spatial prioritization form used by stakeholders in Long Island Sound.

**Figure 3.** LIS spatial prioritization form.

Using the information from the LIS data viewer and *a priori* expertise, participants were asked to select locations within LIS defined by grid cells and provide information based on their opinions/assessments, including: Grid Code, Priority, Ranking Criteria, and Management Issue. While similar, past efforts have been conducted in LIS to solicit data needs in LIS, the utility of this information was limited given that responses where too general to be applicable. Therefore, participants were encouraged to critically evaluate and justify their selections.

### *Prioritization Survey Results and Analysis*

The participant survey data were first imported into a master Excel file to organize the data and explore preliminary patterns. The results, shown in Figure 4, depict the spatial prioritization submissions totaled across all stakeholders. Similar figures were produced for each stakeholder, but are not shown here. The figure depicts the quantity of grid cells scored (number of responses) by Priority (H—High, M—Medium, L—Low) for both the overall Management Issue (Figure 4a) and Ranking Criteria 1 (Figure 4b) categories. We provide only the first criterion as it is the most complete picture, and some respondents did not include second or third Criteria. Individual stakeholder response tables were also calculated, but for brevity are not included here. These results provided initial insight towards the range in quantity of response and the similarities and differences between respondents in perceived needs (Management Issue) and application (Ranking Criteria). It is worth noting that the issue of *Evaluate Management Success* received substantially fewer responses than the five other issues. This is likely due to the fact that respondents felt there were not enough tangible activities a seafloor mapping program might be able to assist with evaluating.

We suspected there may be relationships between the Issues, Priorities, and Criteria that could be used to help further identify priority areas. As the survey data collected were non-normally distributed, we used chi-square tests and nonparametric statistical procedures to test these hypotheses (Sokal and Rohlf 1995). Considering Issues and Priorities first, we used a null hypothesis that there was no inherent relationship and expected the test to reject this if a statistically significant relationship did in fact exist. Chi-square tests are based on

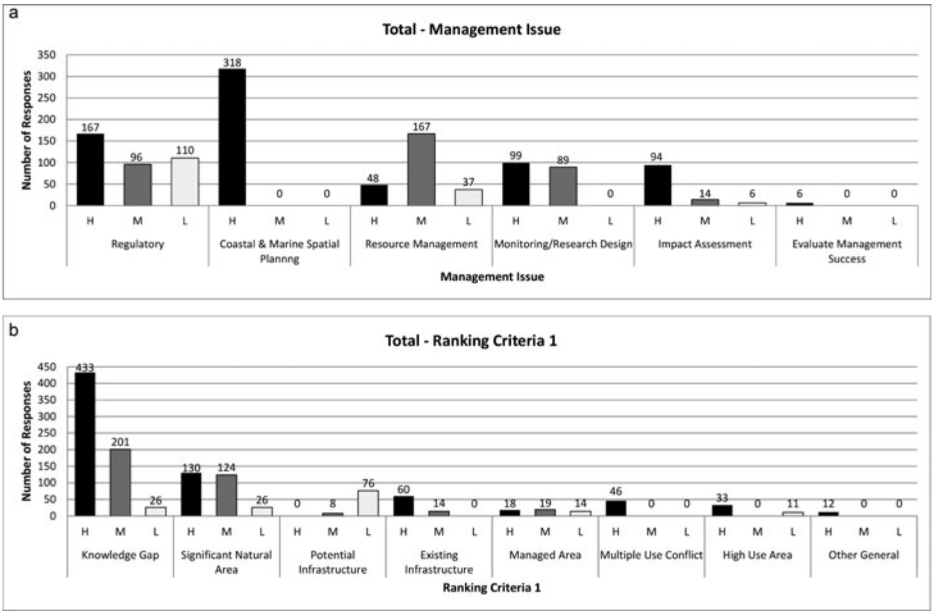



**Figure 4.** a. Spatial prioritization results by Management Issue and ranking category (H = High, M = Medium, and L = Low). 4b. Spatial prioritization results by Ranking Criteria 1 and ranking category (H = High, M = Medium, and L = Low).

comparing a test statistic with calculations of observed, expected, and contingency values. Observed results were compiled directly from the submitted survey data. Expected results reflect what the responses might be in an idealized situation and are defined by:

$$\frac{\text{total observed Priority value}}{\text{total observed Priority responses}} * \text{observed Issue tatal}$$

The contingency value is the variance between the observed and expected results:

$$\frac{(\text{observed} - \text{expected})^2}{\text{expected}}$$

Table 2 lists the observed, expected, and contingency calculations for the Management Issues (as rows) and Priorities (as columns.) Due to the low number of responses for the Issue of *Evaluate Management Success* and null values for medium and low priorities within the Issues of *CMSP* and *Monitoring/Research Design*, we have calculated values but ignored their impacts in the analysis.

A test statistic of 15.51 was determined by standard statistical look-up tables based on a 95% confidence interval and the degrees of freedom (8) within our data given by:

$$(\text{number of rows} - 1) * (\text{number of columns} - 1)$$

(Since the Issue of *Evaluate Management Success* was not included in the analysis, this row was ignored.)

The contingency values in Table 2 (excluding null responses) greater than 15.51 allow us to reject the null hypothesis and confirm there is an association between Management

**Table 2**
Spatial prioritization chi-square test results by Management Issue and Priority

| | *High* | *Medium* | *Low* | **Total** |
|---|---|---|---|---|
| **Chi-Squared (Observed)** | | | | |
| Regulatory | 167 | 96 | 110 | **373** |
| CMSP | 318 | 0 | 0 | **318** |
| Resource Management | 48 | 167 | 37 | **252** |
| Monitoring/Research Design | 99 | 89 | 0 | **188** |
| Impact Assessment | 94 | 14 | 6 | **114** |
| Evaluate Management Success | 6 | 0 | 0 | 6 |
| **Total:** | **726** | **366** | **153** | **1245** |
| **Chi-Squared (Expected)** | | | | |
| Regulatory | 217.51 | 109.65 | 45.84 | **373.00** |
| CMSP | 185.44 | 93.48 | 39.08 | **318.00** |
| Resource Management | 146.95 | 74.08 | 30.97 | **252.00** |
| Monitoring/Research Design | 109.63 | 55.27 | 23.10 | **188.00** |
| Impact Assessment | 66.48 | 33.51 | 14.01 | **114.00** |
| Evaluate Management Success | 3.47 | 1.75 | 0.73 | 5.94 |
| **Total:** | **726.00** | **366.00** | **153.00** | **1245** |
| **Chi-Squared (Contingency)** | | | | |
| Regulatory | 11.73 | 1.70 | 89.81 | **103.24** |
| CMSP | 94.77 | 93.48 | 39.08 | **227.33** |
| Resource Management | 66.63 | 116.54 | 1.17 | **184.35** |
| Monitoring/Research Design | 1.03 | 20.59 | 23.10 | **44.72** |
| Impact Assessment | 11.40 | 11.36 | 4.58 | **27.34** |
| Evaluate Management Success | 1.85 | 1.75 | 0.73 | 4.33 |
| **Total:** | **185.55** | **243.68** | **157.75** | **586.97** |

Issues and Priority beyond random chance. Additional chi-square tests determined relationships also exist between Management Issues and Ranking Criteria and the results are summarized in Table 3. We conclude, therefore:

- The Issue of *CMSP* strongly implies respondents implicitly consider it a *high* Priority. Further, *Multiple Use Conflicts*, followed by *Potential Infrastructure* were the Criteria most strongly associated with it.

**Table 3**
Statistically significant spatial prioritization results by Issue, Priority, and Criteria

| Issue | Priority | Criteria 1 | Criteria 2 | Criteria 3 |
|---|---|---|---|---|
| Regulatory | Low | Potential Infrastructure | — | Existing Infrastructure |
| CMSP | High | Multiple Use Conflicts | No Criteria provided | Potential Infrastructure |
| Resource Management | Medium | Significant Natural Areas | High Use Area | Knowledge Gaps |
| Monitoring/ Research Design | — | Knowledge Gaps | No Criteria provided | No Criteria provided |
| Impact Assessment | — | — | Potential Infrastructure | Significant Natural Areas |
| Evaluate Management Success | — | — | — | — |

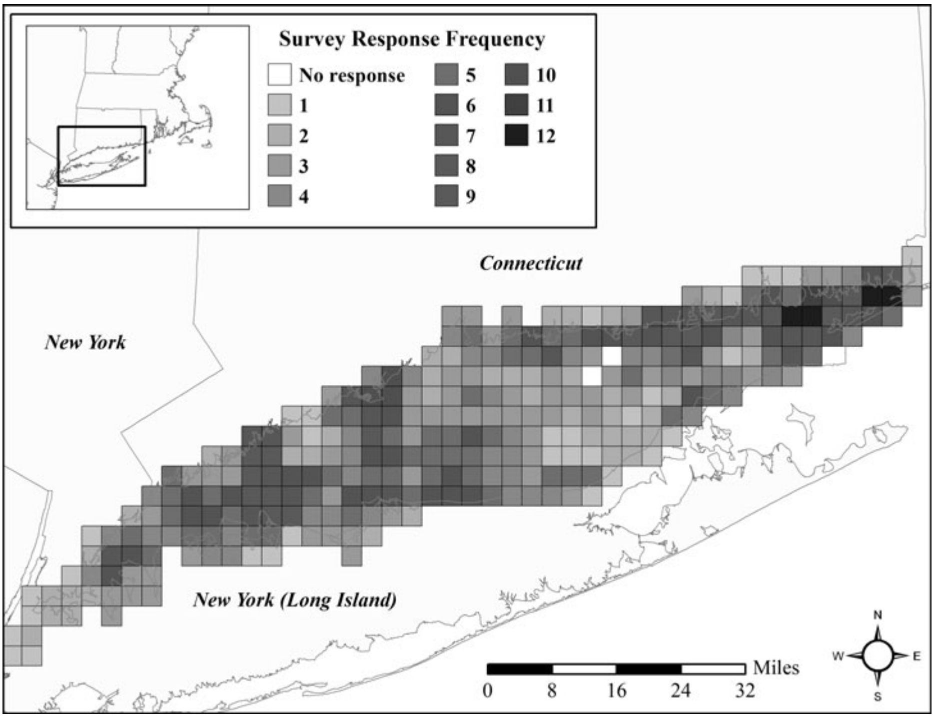



**Figure 5.** Frequency of spatial prioritization results.

- The Issue of *Resource Management* strongly implies respondents implicitly consider it a *medium* Priority. Further, *Significant Natural Areas*, followed by *High Use*, and *Knowledge Gaps* were the Criteria most strongly associated with it.
- The Issue of *Regulatory* strongly implies respondents implicitly consider it a *low* Priority. Further, *Infrastructure* (*Potential* followed by *Existing*) was the criterion most strongly associated with it.

### *Spatial Processing*

After gaining a deeper understanding of the relationships among Issues, Criteria, and Priorities, we conducted analyses to explore the spatial component.

*Basic and Composite GIS Layers.* Survey responses were aggregated into a master spreadsheet, cross-checked for transposition accuracy and used to create basic spatial data layers depicting location and interests of the respondents. The grid cells defined the spatial extents, and the Management Issue, Criteria, and Priority data formed the attribution schema. Separate layers were developed to display both responses by organization and responses by Issue to broadly see where groups were interested and how Issues were distributed. We then created a composite Issue layer by combining the individual layers to provide a unified assessment of the study area on a grid-cell by grid-cell basis. Here, multiple instances of data for the same grid cells are preserved, thus showing all unique responses at that location. It is worth noting that because organizations could identify grid cells for multiple reasons, it was not unexpected to see frequency counts that exceeded the number of participants.

*Merged GIS Layer and Scoring Strategy.* From the composite layer we then created a merged data layer reducing multiple instances of grid cells to a single instance and totaling the Priority and Issue counts. A frequency field captured the number of times each cell received a response (minimum = 1, maximum = 12) (Figure 5).

While the frequency of responses provided some basic insight towards potential areas, a more robust approach was possible since the survey yielded two ways to assign importance to a cell—the explicitly stated priority provided by respondents and the implicitly derived Issue priority from the chi-square analysis. Leveraging this, a composite weighted scoring system was developed. With no reason to assume otherwise, we treated the two prioritization components (explicit and implicit) equivalently with each contributing 50% to the overall score for a cell. Within each component, individual weights assigned to their respective elements were reflected by a 50%–30%–20% breakdown, chosen by best professional judgment. The explicit survey priority weighting applies to responses of *High*, *Medium*, and *Low*, respectively. The implicit Issue priority weighting applies to the responses of *Coastal Marine Spatial Planning*, *Resource Management*, and *Regulatory*—the respective proxies for high, medium, and low priorities from the chi-square analysis. A cell's score is determined by:

$$[\mathrm{Sp} * ((0.5 * \sum(\mathrm{Ph})) + (0.3 * \Sigma(\mathrm{Pm})) + (0.2 * \Sigma(\mathrm{Pl})))]$$
$$+$$
$$[\mathrm{Si} * ((0.5 * \Sigma(\mathrm{CMSP})) + (0.3 * \Sigma(\mathrm{RM})) + (0.2 * \Sigma(\mathrm{R})))]$$

where:
Sp = explicit Survey Priority Weight = 0.5;

Ph = High Priority
Pm = Medium Priority
Pl = Low Priority

Si = implicit Issue Priority Weight = 0.5;

CMSP = Coastal Marine Spatial Planning
RM = Resource Management
R = Regulatory

The composite weighted scoring result is shown in Figure 6, wherein cool colors indicate low scores and warm colors indicate high scores and by extension a higher priority. When compared to the simple frequency plot, more developed areas of significance begin to emerge; however, questions immediately arose regarding whether this could be further refined to better identify zones and/or boundaries. Since the weighted scores seemed to indicate pattern grouping (notable areas of dark grey to black in the western and eastern sections of LIS), a geospatial clustering analysis was performed.

*Geospatial Clustering Analysis.* The esri ArcGIS Geostatistical Hot Spot Analysis tool was used to process the weighted scoring results and determine if statistically significant clusters or patterns of values exist that would more definitively represent areas to prioritize (ESRI 2012). At a basic level, the tool works by looking at each grid cell within a context of neighboring cells. A cell with a high score may be interesting, but to be statistically significant, it would need a high score and be surrounded by other cells with high scores as well.

The process returns a statistic ($z$-score)—in essence, a standard deviation value—for each feature in the dataset. For statistically significant positive $z$-scores, a larger $z$-score is

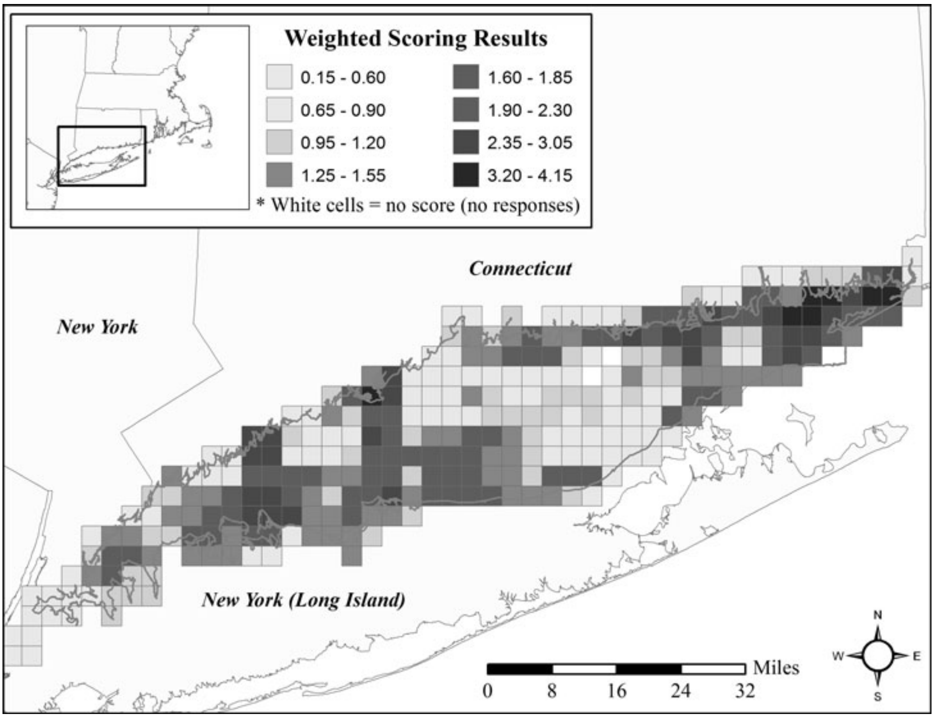



**Figure 6.** Composite weighted scoring of spatial prioritization results.

indicative of intense clustering of high values. Conversely, statistically significant negative *z*-scores are indicative of intense clustering of low values. The tool also provides a probability statistic (*p*-value) that measures whether a spatial pattern reflects random chance. In areas with appropriately small *p*-values and either a very high or a very low *z*-score, it is unlikely that the spatial pattern is completely random and thus is a significant cluster. Application of the tool required the consideration of how to define the neighborhood of cells by using a moving window of influence based on a fixed distance. Features within the specified distance are weighted equally and features outside the specified distance are ignored. We determined the optimal distance by iteratively running a series of spatial autocorrelation processes with varying distances and looking for results that converged to a maximum standard deviation value (*z*-score). Based on the results in Table 4, we used a distance value of 11,000 m.

**Table 4**
Distance thresholds used to capture the maximum clustering effect

| Distance threshold (m) | Global Moran's Index Summary | Expected Index | Variance | *Z*-score | *P*-value |
|---|---|---|---|---|---|
| 7,500 | 0.468651 | –0.003378 | 0.000963 | 15.2133 | 0 |
| 10,000 | 0.30188 | –0.003378 | 0.0004 | 15.2539 | 0 |
| 11,000 | 0.30188 | –0.003378 | 0.0004 | 15.2539 | 0 |
| 12,000 | 0.243628 | –0.003378 | 0.000292 | 14.4494 | 0 |

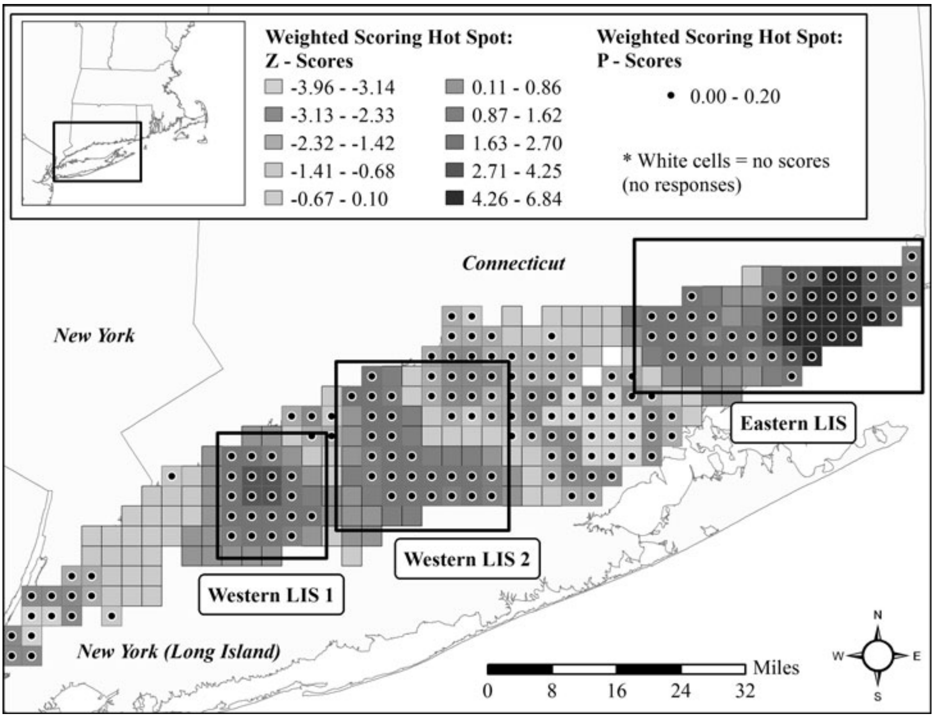



**Figure 7.** Spatial prioritization results from Hot Spot Analysis.

Figure 7 shows the results depicting a more refined delineation of clustered high and low scores. $z$-scores are color coded with black and dark grey corresponding to "hot" (highly positive) standard deviation values ($>1.28\sigma$). $P$-values of greater than 0.2 are symbolized as check-marks and denote a confidence interval of at least 80%. The combination of these two statistics allows us to conclude there are statistically significant clusters of grid cells (identified as Western LIS 1, Western LIS 2, and Eastern LIS) that represent a reasonably robust demarcation of priority focus areas.

### *Priority Focus Areas and Survey Results*

By comparing the priority boundaries and the gridded versions of the survey responses, a clearer perspective can be gained on the issues and criteria that prevailed in these areas where future mapping and analysis should be geared to address.

In the Western LIS 1 priority area:

- *Coastal Marine Spatial Planning, Monitoring/Research Design*, and *Resource Management* (respectively) were the top three issues, accounting for over 70% of the survey responses.
- The predominant criteria (spanning all recorded issues) involved *Knowledge Gaps* and *Significant Natural Areas*. Other criteria suggest interest in *Uses* and *Infrastructure*.

- Several comments provided by respondents specifically identified infrastructure alternatives analysis, reefs, scientific interest, and lobster/fisheries resources as points for consideration.

In the Western LIS 2 priority area:

- *Regulatory, Coastal Marine Spatial Planning* and *Resource Management* (respectively) were the top three issues, accounting for approximately 80% of the survey responses.
- The predominant criteria (spanning all recorded issues) involved *Knowledge Gaps* and *Significant Natural Areas*. Other criteria suggest interest in *Uses* and *Infrastructure*.
- Several comments provided by respondents specifically identified infrastructure alternatives analysis, sediment management, and lobster/fisheries resources as points for consideration.

In the Eastern LIS priority area:

- *Resource Management, Regulatory*, and *Coastal Marine Spatial Planning* (respectively) were the top three issues, accounting for approximately 80% of the survey responses.
- The predominant criteria (spanning all recorded issues) involved *Knowledge Gaps, Use,* and *Significant Natural Areas*. Other criteria suggest interest in *Infrastructure*.
- Comments provided by respondents specifically called out eelgrass, species management, sediment management and reefs as points for consideration.

It is worth noting that across all areas, the most frequent management issues and criteria were similar, albeit with slight differences among their relative orders. This suggests that a similar approach or approaches to a seafloor mapping program could be utilized in LIS rather than having to design unique approaches in different areas.

### *Participatory Refinements*

The findings from these analyses were presented to the LIS stakeholders. The results of the survey and subsequent spatial analyses were discussed and feedback was solicited from the group to determine if the results sufficiently captured the perceived priority needs and locations. Based on these discussions, priority area extents were modified to better reflect natural topographic and geographic boundaries rather than the aliasing inherent in the gridded data used for the survey. The gridded data were converted to a point layer and processed via an Inverse Distance Weighted smoothing algorithm to create a refined priority map (Figure 8) to direct and develop future workplans for undertaking the collection of new data and products.

### *Limitations of the LIS Spatial Prioritization Process*

While the technique developed for spatially prioritization for LIS was innovative and quantitative compared to other more qualitative approaches, several challenges were identified at the conclusion of the process. It is recommended these be addressed in subsequent efforts.

1. *Spatial processing challenges*:
   - The spatial analytical approach used is susceptible to edge effects along the boundary of the project extent where data were absent.

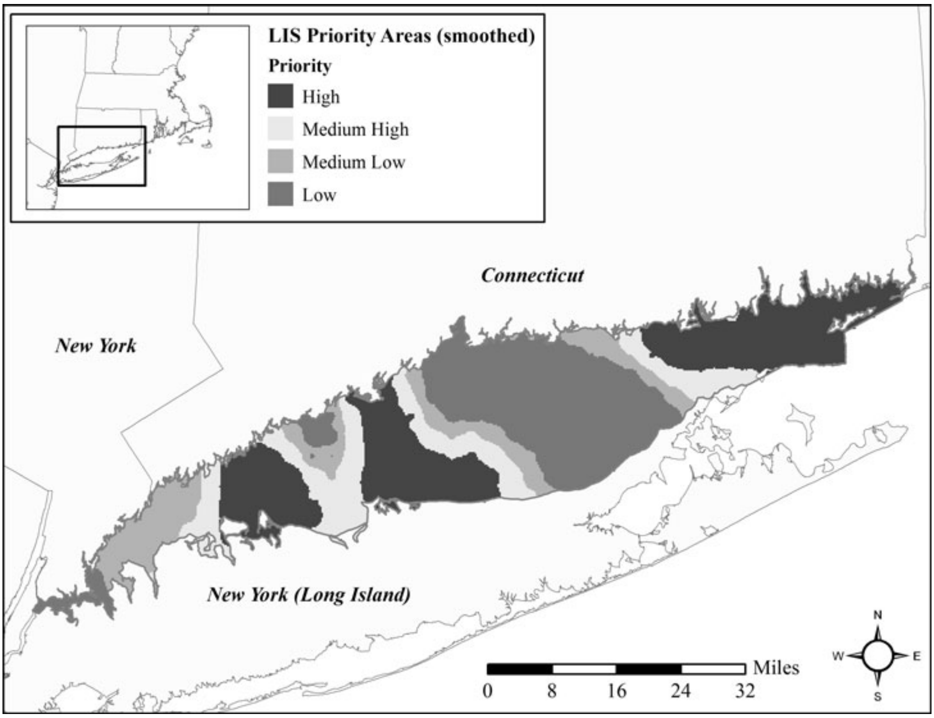



**Figure 8.** Spatial prioritization smoothing results using Inverse Distance Weighting.

- The spatial prioritization results are scale dependent based on the size of the grid cell (4 × 4 km) used to query stakeholders.
- No procedures were implemented during the prioritization survey to require, limit or equalize the number of entries input by stakeholders. Our analysis of the data indicated (results not included) that the priorities of some stakeholders were unequally distributed throughout the project extent, reflective of their respective jurisdictional boundaries (e.g., New York stakeholders favored New York state waters).

2. *Participatory Refinements*:
   - The priority areas identified through the spatial processing steps do not necessarily reflect or account for regions of high ecological diversity or critical habitats (e.g., high natural topographies, habitats, geologic structures/formations) and therefore represent an initial guide to areas of high interest.
   - It is wholly possible and acceptable to reasonably adjust or modify these areas to capture unique phenomena or leverage matters of practicality or project intent (e.g., research questions, optimize survey design, and cruise plan).
3. *Tool Improvements*:
   - Given the time constraints of the project, an optimum spatial prioritization tool was not possible. Web-based tools that facilitate the capture of information would benefit the process of soliciting input from stakeholders. This includes practical tools that allow the user to select and populate multiple grid cells simultaneously, dynamic results display to indicate where information has been completed, and the ability to save and track entries. Furthermore, a means of

equalizing the number of entries submitted by individual stakeholders would improve equitability.

## Conclusion

A recent U.S. Executive Office policy directive, Stewardship of the Ocean, our Coasts, and the Great Lakes (Executive Order 13547), has invigorated U.S. coastal and marine spatial planning by federal and state agencies. The Executive Order was intended to encourage science-based tools, capabilities, and analysis that can be used to address ocean management challenges, conservation objectives, and economic development—elements fundamental to sound coastal management efforts. This U.S. policy parallels other international efforts including the United Kingdom's Marine and Coastal Access Act (United Kingdom 2009) and the European Union's proposal for maritime management (European Commission 2013). However, while the legislative and policy directives for coastal management have largely been instituted, the underlying mechanisms for implementing and collecting the information required to conduct spatial planning remains ambiguous. Our efforts were a direct response to the absence of accepted methodologies in this regard; therefore we undertook the development and implementation of a quantitative process to further coastal and ocean planning in LIS.

Seafloor mapping data provide a fundamental, foundational information source needed to support a range of coastal management applications, however, the breadth and diversity of these needs poses significant challenges. Creating a unified collection strategy for LIS was one of the principle objectives to minimize duplication, maximize efficiency, and minimize costs. Historically, much of the existing seafloor mapping data collected for the coastal zone have been conducted to support a targeted need rather than considering a host of applications. Given that strategic planning to address these factors was typically not conducted, spatial coverage is generally incomplete and collected to such different standards that it precludes data unification. While there are certainly instances where data need to be collected for an exclusive purpose, in many instances better results can be achieved by gathering the collective users in the planning process.

The implementation of the spatial prioritization process in LIS was instrumental in guiding the subsequent project planning details. The results of this prioritization exercise were influential in elevating LIS to a higher priority status in federal and state planning processes (e.g., ship allocation), and providing the explicit identification of locations requiring additional directed effort by National Oceanic and Atmospheric Administration (NOAA) and other partners. For example, through our evaluation of the existing seafloor mapping data for LIS, we determined the presence of large data gaps, and also that many previously collected data sets did not provide sufficient resolution or data type to support their reuse in the LIS mapping project. These conclusions were critical in identifying new survey collection areas that were subsequently mapped by the NOAA ship *Thomas Jefferson* and academic partners in 2011–12. Moreover, new surveys efforts were designed to collect data and maximize the utility of seafloor mapping products to better address the management needs identified through the spatial prioritization process. In doing so, the LIS project ensured that newly collected data would better support a broader range of uses (Ocean and Coastal Mapping Integration Act 2009) and therein embrace the concept of Integrated Ocean and Coastal Mapping (IOCM)—"Map once and use many times."

While many coastal states have recently completed or engaged in developing strategic management plans for their coastal waters (i.e., Rhode Island, Massachusetts, Oregon, California, and Washington), it is anticipated that additional states will be grappling with similar undertakings in the near future. Meanwhile, the U.S. Bureau of Ocean Energy Management is actively pursuing the development of alternative energy siting evaluations along the Outer Continental Shelf in federal waters of the United States. To address this growing need, the approach presented herein for LIS provides a methodology to synthesize existing work, capture and document disparate stakeholder needs in a geospatial context, and analyze the results in a defensible, quantitative way to look for areas of convergence. While this approach was formulated to address the specific needs of LIS, we believe it can be transferred to other coastal regions, can be scaled to larger or smaller geographies, and can be customized to address the unique challenges of a given locale or region. Feedback provided by groups and individuals that participated in the LIS prioritization confirmed the process was successful in converging disparate priorities to identify locations of highest importance and capture the underlying needs and justification of those locations for seafloor mapping data. By implementing the spatial prioritization methodology developed for LIS, management and planning agencies can focus subsequent planning efforts and investment in data collection toward areas of greatest need so as to capture information that benefits the broadest range of applications.

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