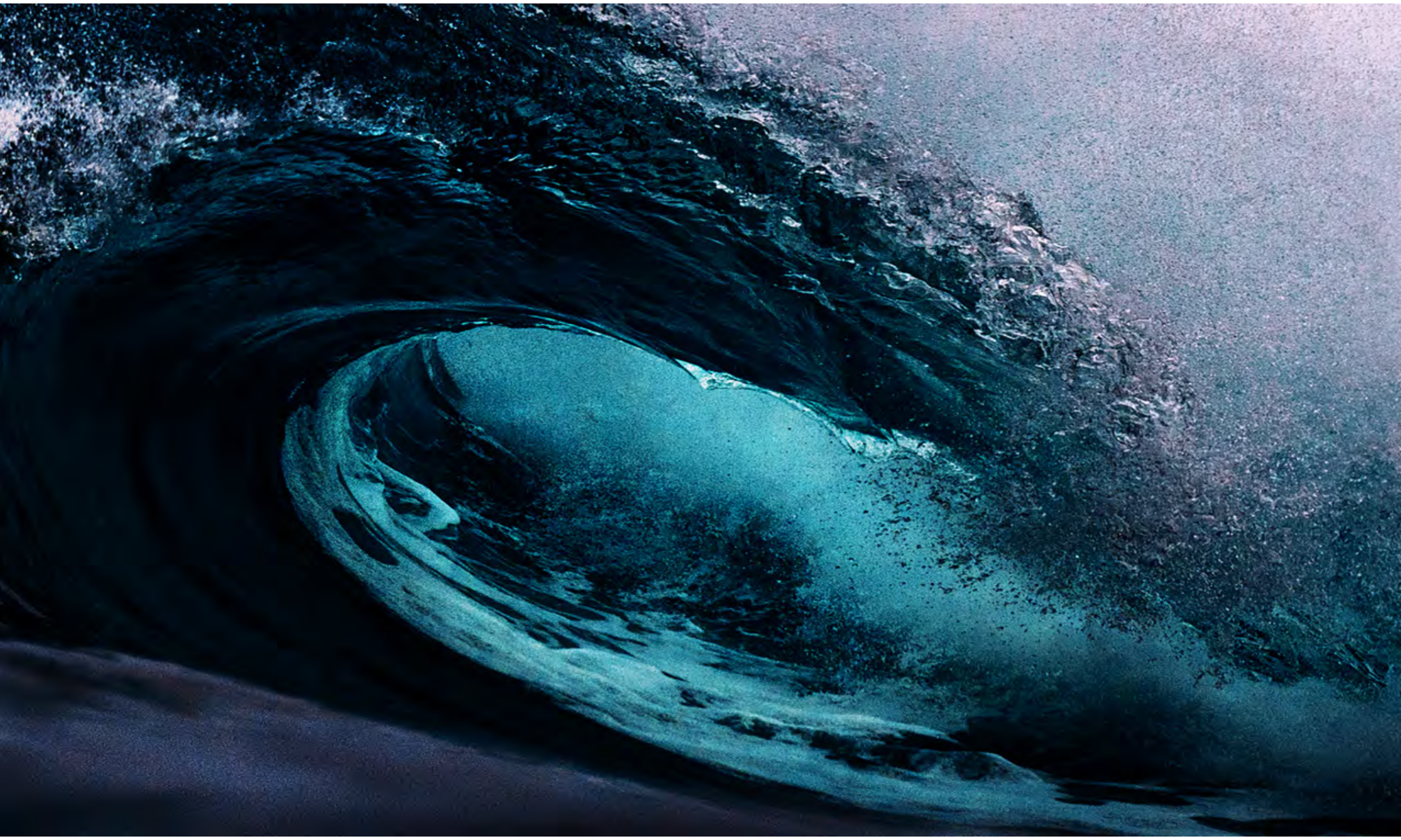
Ecosystem-Based Management

An analysis of national needs and opportunities



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Ecosystem-Based Management

An analysis of national needs and opportunities

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ABSTRACT

Through a partnership with the NOAA National Center for Coastal Ocean Science and the Cooperative Institute for the North Atlantic Region, we investigated present implementation status, research needs, and perceptions of ecosystem-based management (EBM) in coastal regions of the US. We were charged to perform a high-level analysis to identify research needs that, if fulfilled, would enhance the implementation of coastal EBM strategies.

One of the purposes of this project was to provide an update to NOAA's Regional Ecosystem Research Prospectus, a document that has helped guide regional coastal science to address EBM and other management needs. We relate our results to the 2008 Prospectus to provide information on the persistence of some needs, evolution of thinking on some of the re-occurring needs, and the emergence of new science needs.

We synthesized responses to an online survey and semi-structured follow-up interviews with coastal scientists, managers, and policy makers, alongside review of local and regional planning and science strategy documents to reveal cross-cutting science that could enhance coastal EBM implementation.

We identified needs for *ecosystem science* to improve the understanding of ecological connectivity and cascading effects of change and *socio-ecological science* to support decision making for equity and sustainability. We also learned of needs for strategies in *governance and incentives* to encourage cooperative research development and management. Our sources revealed a critical need for applied *resilience science* to realize regional goals for ensuring ecosystem and human well-being.

Our process revealed an enthusiasm among coastal scientists, managers, and policy makers for applying EBM strategies to improve the way we engage with coastal resources.

Contents

Introduction

Regional coastal marine research can broaden scientific understanding of how natural processes and human-influenced perturbations propagate from the local scale to affect larger ecosystems and influence the global oceans. Cooperation of coastal managers and scientists at a regional scale will help foster better understanding of multiple interacting stressors across boundaries and support broader management objectives that consider the entire ecosystem. In 2008, the Regional Ecosystem Research Prospectus (2008 Prospectus) was drafted by NOAA's National Centers for Coastal Ocean Science (NCCOS). The report reviewed regional coastal research programs and science needs for Large Marine Ecosystems (LMEs) of the United States. The document served as an internal guide for NCCOS to focus and prioritize research projects that would benefit regional marine science and management. An emphasis of the 2008 report was to review the current regional-scale marine research initiatives and to promote coordination among agencies. This report is intended to update and expand upon the 2008 Prospectus with the perspective of identifying science that would enable or enhance ecosystem-based management (EBM).

Ecosystem-based management works along natural ecosystem boundaries, instead of administrative boundaries (Slocombe, 1993), and in relationship with human and ecological structures (Link and Browman, 2017). At the time of the 2008 Prospectus, a broader ecosystem approach to coastal marine management and better integration of science and management priorities were being increasingly encouraged (Boesch, 2006; Murawski, 2007), though a lack of resources and established methods were major obstacles to implementation (Taylor, 2008). This report discusses practitioners' perceptions of opportunities and challenges as EBM has developed and reviews the critical and emerging science needed to support regional EBM.

Foundations of Ecosystem-Based Management

“Public land policy does not begin with the land,
but with man’s dependencies upon it.”

- Lynton Caldwell 1970

Decision making in an ecosystem framework is not simply science-based resource management. Rather, it is a “fundamental reframing of how humans may work with nature” (Grumbine, 1994). Major principles of the ecosystem approach to managing human influences in the natural environment have been discussed for decades (e.g., Caldwell 1970, Holt and Talbot 1978, Mangel et al. 1996) and served as precursors to the EBM framework (Long et al., 2015). Originally conceived in terrestrial environments, EBM has been relatively recently embraced in marine environments. Formal definitions of EBM vary slightly (e.g., Slocombe 1993, 1998, McLeod et al. 2005, Wondolleck and Yaffee 2012), but the key elements include acknowledging the lack of boundaries (geographic, jurisdictional, or economic) between ecological and social systems and promoting decision making that regards the complex interconnections that exist. After a call to more precisely define *marine* EBM (ORAP, 2013), practitioners launched efforts to more formally characterize the concepts and principles that make up the EBM approach (e.g., ORAP 2013, Dell’Apa et al. 2015, Long et al. 2015). For the purposes of this project, we devised the following concise operational definition of EBM to guide our information gathering and identification of critical science needs.

Ecosystem-based management is an interdisciplinary approach to environmental management that considers the multitude of interconnected processes and the environmental, social, and economic trade-offs associated with actionable goals for restoration and protection of healthy, productive, and resilient ecosystems.

Our definition built upon the foundational concepts of “ecosystem management” (Grumbine, 1994), the definition of EBM for the oceans by COMPASS (McLeod et al., 2005), and other key features and developments described in the literature (e.g., Costanza 1998, Arkema et al. 2006, McLeod and Leslie 2009, Kelble et al. 2013, Dell'Apa et al. 2015, Long et al. 2015, ICES 2016, Harvey et al. 2017). Similar principles to those included in the EBM framework are captured in concepts such as holistic management, coupled social-ecological systems, marine spatial planning, and integrated coastal zone management. Therefore, we proceed referring to EBM as a broad concept not strictly owned by the label of EBM or any other terminology, including our definition.

Marine EBM can be thought of as "a framework for managing people's interactions with the environment" (Leslie, 2018). A coordinated commitment to EBM could improve both coastal ecosystems and human well-being (Agardy et al., 2011). There is an increasing responsibility on scientists to better grasp the intricacies of policy-making to ensure relevant scientific guidance in light of community priorities, tradeoffs, and uncertainty (Foley et al., 2010; Cormier et al., 2017; Epstein et al., 2018). The disconnect between ecosystem boundaries and governance boundaries is a common challenge for management projects (Leslie et al., 2015). However, the collaborative and adaptive approaches central to EBM may help facilitate cooperation where ocean governance is hindered by conflict (Tiakiwai et al., 2017).

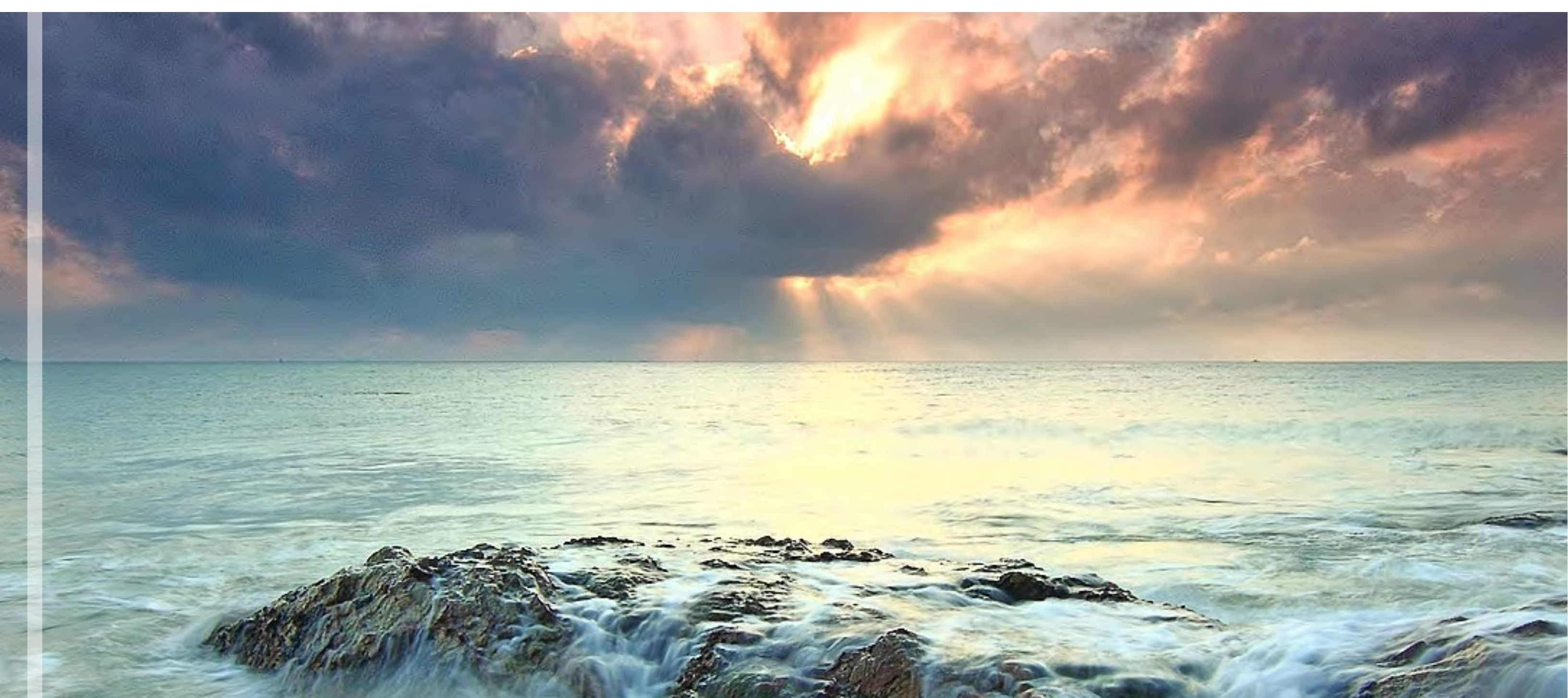
Evolution of Ecosystem-Based Management in the US

Ecosystem-based management was established as a national priority objective adopted under the National Ocean Policy (NOP) by executive order (The White House Council on Environmental Quality 2010, Executive Order 13547). Under this mandate, progress was made toward developing guidance and establishing partnerships for EBM implementation, though EBM actions made slower progress than did other priority objectives (The White House, 2015). Regional planning bodies were established in response to the NOP and they drafted some of the nation's first regional coastal management plans expressly focused on implementing EBM (e.g., Mid-Atlantic Regional Ocean Planning Body 2016, Northeast Regional Planning Body 2017, American Samoa Ocean Planning Team 2018).[1]

[1] The 2018 repeal and replacement of the National Ocean Policy with the Ocean Policy to Advance the Economic, Security, and Environmental Interests of the United States (Executive Order 13840) disbanded the regional planning bodies and refocused federal emphasis from stewardship for ecosystem resilience to promoting ocean industry and national security objectives.

NOAA's Integrated Ecosystem Assessment (IEA) program promotes the EBM framework with efforts to summarize the status of regional ecosystems and evaluate risks and management approaches to inform decision making (Levin et al., 2013). Annual reports in five US regions are prepared by the IEA program and used to support the ecosystem perspective in regional management plans, particularly fisheries planning (Harvey et al., 2020; Pacific Fishery Management Council, 2020). Any discussion of marine EBM would be incomplete without considering how ecosystem-based fisheries management (EBFM) has influenced the broader, holistic view of marine resource management in the US. Some of the greatest strides for EBM in the US have been made under NOAA's EBFM policy (NOAA Fisheries, 2016). The EBFM policy expanded fisheries management beyond single species to consider the full system of fisheries and stocks. These efforts require the incorporation of ecosystem processes and socio-ecological tradeoffs into management advice for fisheries resilience. However, determining the relationship between EBM initiatives and EBFM can be complicated by this crossover (Wondolleck and Yaffee, 2017).

Until relatively recently, EBM was viewed as a good idea without a clear approach for implementation (Crowder and Norse, 2008). Currently, EBM is being attempted in multiple coastal ecosystems, but it has struggled with unclear definitions, differing perspectives, and incomplete application (Long et al., 2015) and is not yet widespread (Link et al., 2019). In many cases, EBM is still in its early, trial-and-error phases (Samhouri et al., 2014; Leslie, 2018). While EBM has progressed, demands remain for improving and expanding cross-cutting science and explicit acknowledgment of the rationale and tradeoffs associated with management actions in complex social-ecological systems (Markus et al., 2018). (McLeod and Leslie, 2009b; Alexander et al., 2019)



State of EBM science - in a nutshell

To fulfill the vision of EBM, chemical, biological, physical, and social factors must be considered simultaneously. Despite decades of acknowledgement from practitioners, this *interdisciplinary* research is making slow progress in marine EBM, perhaps because of a lack of operational guidance or incentives to undertake such work (McLeod and Leslie, 2009b; Alexander et al., 2019), but is increasingly urgent to support marine resources governance (Markus et al., 2018).

Environmental perturbations, whether anthropogenic or natural, have cascading effects on socio-ecological systems. Science and monitoring to understand these *interconnected processes* are critical to informing any resource management response (Liu et al., 2007). EBM requires more than an aggregation of data, new research is needed to better understand the intersections of biophysical and human dynamics (Leslie, 2018).

Acknowledging and managing *tradeoffs* requires science to project cause and effect relationships within and between the natural environment and human uses. EBM activities could be supported by new tools (e.g., ecosystem models, tradeoff analyses, decision-support tools) to evaluate tradeoffs of proposed management actions (Leslie and McLeod, 2007) and, when used as part of an effective governance and communication practice, can build trust and manage expectations among stakeholders (Tallis et al., 2010).

EBM requires a long-term commitment from cooperative multi-level management (Berkes, 2012; Leslie et al., 2015) to work toward clear and *actionable goals*, based on societal values (Alexander et al., 2019). Many feasible management actions may promote goals of ecosystem preservation or restoration, but additional research is needed into how governance processes can more efficiently incorporate and adapt to new scientific information (McLeod et al., 2005) and incentivize sustainable behaviors (Lubchenco et al., 2016).

A *healthy, productive, and resilient ecosystem* is the ultimate goal of EBM. Reshaping of ecosystems and human behaviors by climate change may alter how we define and achieve this goal. Therefore, research is also needed to identify ecological thresholds and enable more responsive management strategies to respond to climate change in marine ecosystems (Mumby et al., 2017).

Scope and Methods Summary

Through a partnership with the NOAA National Center for Coastal Ocean Science (NCCOS) and the Cooperative Institute for the North Atlantic Region (CINAR), we investigated present implementation status, research needs, and perceptions of ecosystem-based management (EBM) in coastal regions of the US. We were charged to perform a high-level analysis to identify research needs that, if fulfilled, would enhance the implementation of coastal EBM strategies.

One of the purposes of this project was to provide an update to the Regional Ecosystem Research Prospectus (2008 Prospectus; NOAA National Centers for Coastal Ocean Science 2008), a document that has helped guide regional coastal science to address EBM and other management needs. The major objectives of the science needs described in the 2008 Prospectus were to expand regional management approaches and coordination and to develop models to support ecosystem-level management. We relate our results to the 2008 Prospectus to provide information on the persistence of some needs, evolution of thinking on some of the re-occurring needs, and the emergence of new science needs.

Process

The content of this report, including this chapter, reflects our compilation and synthesis of US-wide information from the following sources[2]:

- Responses and comments provided by scientists, managers, and policy makers to an online survey that we designed (Appendix B)
- Semi-structured follow-up interviews with selected survey respondents to elicit additional examples and details (Appendix A; Figure A3)
- Informal interviews and discussions with practitioners, such as part of scientific conference sessions on EBM and ecosystem-based fisheries management (EBFM)

[2] Detailed methods are described in Appendix A of the report.

- Publicly available coastal management plans, strategy documents, and requests for research proposals within the scope of EBM, often at the regional level
- Published literature, including reviews, case studies, and agency white papers and reports
- Websites of organizations and partnerships involved in coastal science and management planning
- Input from selected external experts invited to review regional chapter drafts, including some members of an advisory group set up for this project

The primary sources of information used to develop this report were the responses to our online survey (Appendix B) and the semi-structured follow-up interviews (Appendix A, Figure A3) that we conducted with coastal scientists, managers, and policy makers. This approach was designed to help us identify critical science needs for EBM in a format that allowed for open-ended responses to encourage expressions of the current thinking across many topics. We also elicited professional perspectives on EBM throughout the US by asking respondents to describe experiences, science needs, perceived barriers, and opportunities to enhance EBM strategies at a local-to-regional scale. By combining the local and regional scale information, we also sought to achieve synthesis at the national level. Open-ended survey responses were coded based on the key ideas in the text. Survey and interview responses were then separated by region and organized by topic. Our research team evaluated and compiled responses and identified the most salient research themes. We presented survey data and analyses at several conferences and seminars where we led discussions to gather input from other practitioners in the field.

Our survey identified broad science needs and illustrative examples for regions but was not intended to generate a comprehensive set of recommendations. The survey was designed to gather input from a diverse set of scientists, managers, and policy makers who voluntarily offered their current views on science needs to advance EBM. In most regions, we obtained sufficient responses to formulate many examples to clearly illustrate the science needs. However, the responses are not the only critical science needs, nor are they ranked by priority.

To supplement the online survey and follow-up interviews and discussions, we compiled reports, management plans, requests for proposals, and journal articles that covered critical science needs and priorities at the regional level. We referenced these to substantiate and augment the science needs identified in the surveys and interviews. In some cases, the research team and external reviewers provided details and context for the more general recommendations provided in survey responses and reports.

Themes of EBM Research Needs

In our evaluation of critical science needs for EBM at a regional level, we recognized several science themes that were common across regions. These national-level themes are nested to represent their interconnectedness (Figure 1) and served as broad categories to organize the specific needs and examples across regions.

Ecosystem Science is the core theme that includes biogeochemical and physical research aimed at understanding ecological system elements and their interrelationships. *Socio-Ecological Science* is the theme that encompasses ecosystem science and research into human dimensions of EBM that aims to link human-environment interactions. The next theme is *Governance and Incentives,* which covers decision drivers, including opportunities for and constraints to EBM as influenced by institutional structures, capacity, and procedures. Finally, *Resilience Science* involves all three of the previous themes to reflect the overarching idea of integrated science to understand vulnerability, compounding impacts of change, and effects on both ecosystem and human community resilience. While we did not dedicate a section in the chapters to resilience science, we recognized the familiar theme for science to understand and achieve ecosystem resilience communicated within the vast research needs of the other categories. These categories, for the most part, are a convenience for giving structure to this report. Ultimately, EBM requires cross-cutting science and the research and tools to realize EBM will, to varying degrees, be integrated across categories.

Figure 1. National-level hierarchy of critical science themes

Guide to the Report

This report identifies significant coastal issues that require additional natural and social science understanding to enable EBM implementation at local to regional scales. First, we provide an overview of EBM and information about data collection and synthesis methods used to develop this report. Next, the National Synthesis chapter presents select, national-level survey results and highlights common themes of critical science needs that appeared across multiple regions. This is followed by eight chapters that present our analyses at the regional level. Each regional chapter is intended to provide enough context to stand alone, and presents topics and examples of science specific, to varying degrees, to the region of interest. Some topics that were identified as a need in some regions may not appear in other regions because they are already well-researched, not presently considered critical to EBM implementation there, or simply were not mentioned. Some topics are similar among several regions, nationally, or even internationally. While we provide a wide-ranging list of science topics and examples throughout this report, it is not intended to be a comprehensive list of science needs and does not exclude other regional or national research that may help achieve EBM objectives.

Guide to the Regional Chapters

In the eight regional chapters, we provide a snapshot of research needs that scientists, resource managers, and policy makers have suggested would enable or enhance coastal EBM strategies in locations throughout the region. These chapters are intended to provide enough context to stand alone as a resource for the region. First, we highlight some of the existing features and recent progress in EBM strategies within the region. Next, we summarize the online survey results and interviews, including respondents' perspectives on EBM issues, priorities, and research needs to promote progress for EBM. The section reports what surveyed and interviewed practitioners said and identifies shared sentiments. We also highlight similar priorities and objectives appearing in regional literature, including local and regional management plans and strategy documents. Second, we present our regional synthesis of priority science that would support EBM strategies arranged within the first three themes of *Ecosystem Science, Socio-Ecological Science, and Governance and Incentives* (Figure 1). We describe specific topics that reflect the nuance of the needs identified from sources within the region, with subtopics or examples of research relevant at the local to regional scale.

National Synthesis

Perceptions of EBM Implementation in the US

In total, we analyzed 216 survey responses and conducted follow-up interviews with 27 of these respondents. The majority of the 181 participants that responded with their work title identified as scientists (73%), with those identifying as policy makers and/or resource managers (not including those also identifying as scientists) making up the remaining 27% (Figure 2). Ninety-two percent of participants responded that they provide guidance for management decisions in coastal marine resources. EBM was described as a goal in the work of 202 respondents (94%) and currently being implemented in the work 156 respondents (77%).

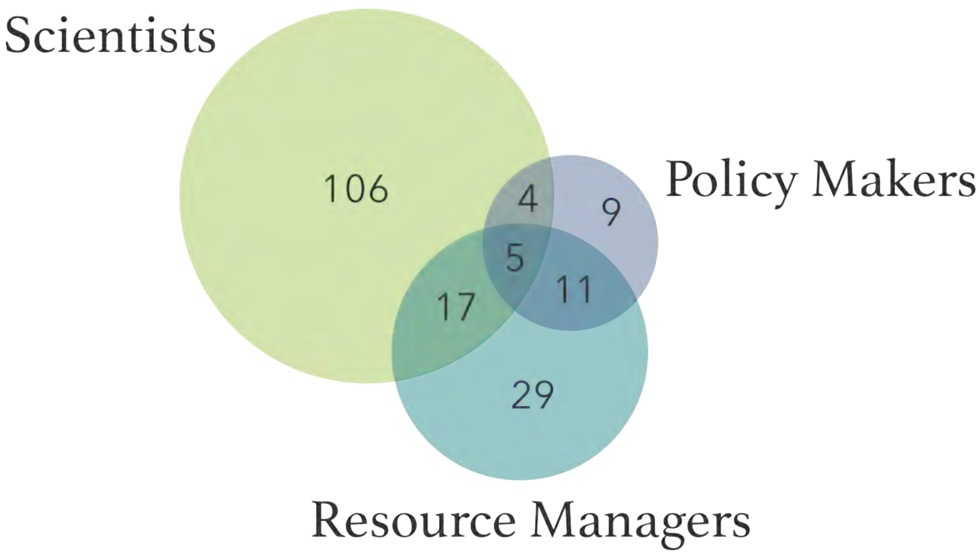


Figure 2. Self-identified work titles (n=181, non-response=35).

Our project focused on identifying science needs to support EBM implementation. Science investment is undoubtedly critical, but it alone is not sufficient to enable the strategic approach needed to achieve EBM objectives (Wondolleck and Yaffee, 2017). Two of the survey queries provided rich information on perceived challenges to EBM implementation. We highlight these concerns because they had great consistency across regions. Issues discussed here were commonly cited by respondents across regions and appeared in the 2008 Prospectus, strategic and planning documents, and the open literature review.

Since the challenges of implementing EBM programs are widely recognized, we asked respondents to rank the difficulty of achieving specific elements of such programs, as derived from our operational definition (see above). Forty-six percent of survey respondents ranked *implementing an interdisciplinary approach* as the most difficult aspect of EBM to achieve (Figure 3). Follow up interviews clarified that most respondents defined this to mean the inclusion of both biophysical and social scientists and managers. Some responses referred to the inclusion of multiple agencies and groups, adding policy makers and legal experts to the interdisciplinary efforts. Other elements commonly cited among the most difficult were *developing actionable goals* and *understanding interconnected processes,* which were ranked either 4 or 5 by 48% and 41% of respondents, respectively.

To elaborate on survey responses, follow-up interviewees were asked to describe why they chose a specific element as the most difficult. Comments commonly described the difficulties of communicating across disciplinary boundaries and agency roles and acknowledged a need for ways to overcome the silos within institutions. Further, ineffective communication was also reported to hinder discussions of tradeoffs, interpretation of socio-ecological connections, and cooperative goal setting. The 2008 Prospectus highlighted the need for greater interagency coordination – the results of our study suggested this need persists. There were signs of encouraging trends. One respondent noted that sustainability programs with goals of enhancing cross-cutting research and communication were emerging and making progress. Similarly, another respondent commented that people were more open to recognizing ways to involve multiple perspectives to approach ecosystem issues than in the past. An interviewed respondent acknowledged that growing pressure from funders for interdisciplinary research is helping to cultivate the cooperative networks that are critical to achieving EBM goals.

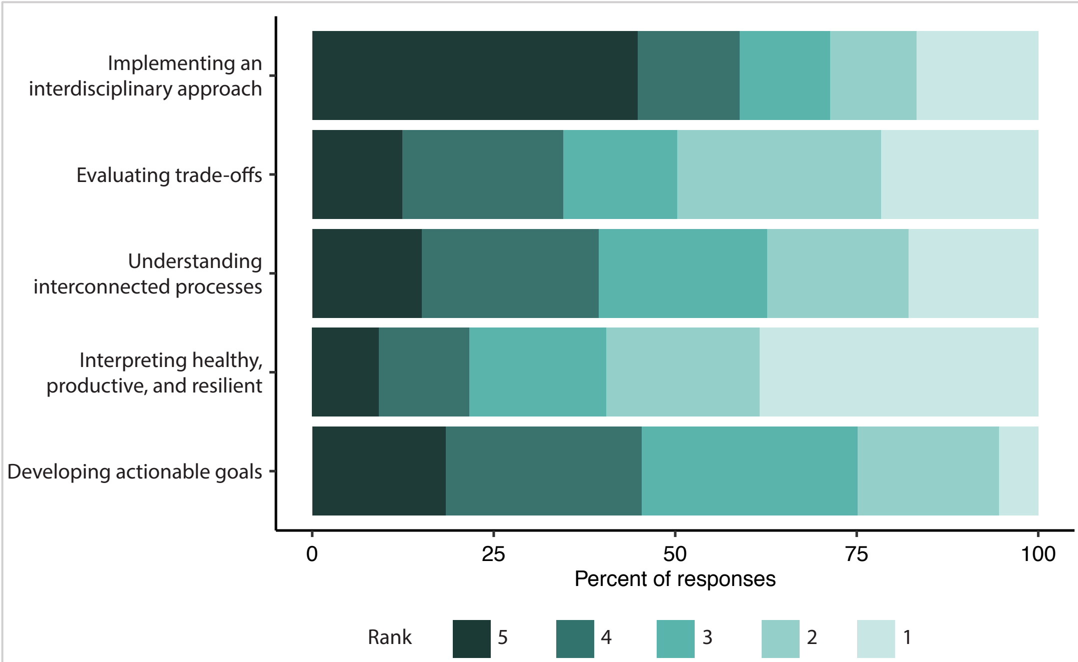


Figure 3. Perceived relative difficulty of EBM attributes where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=185). Note: this survey query was not specific to location or region.

In responses to the survey question, *What is the biggest non-science barrier to EBM?* the most common write-in responses described constraints to agency cooperation and coordination due to existing institutional structures (30%) and limited commitment of financial and personnel resources (29%) to conduct the necessary science and synthesis required to implement EBM (Figure 4). Survey responses and interviews also suggested scientists and managers were, with mixed success, challenged to identify the most effective ways to improve coordination of stakeholder and management objectives and to garner sufficient support of leadership. One survey response summarized a common reaction to the question of the biggest non-science barrier to EBM as "coordination and priority setting in a climate of uncertain funding."

Figure 4. Coded themes of responses describing non-science barriers to EBM (SQ42, n=167). The size of words is relative to frequency of the code. Note: this survey query was not specific to location or region.

According to survey responses and interviewed respondents, uncertainty and misconceptions about what EBM entails can also impede implementation. Some respondents expressed confidence that an ecosystem approach could be well supported at local levels and perceived an increasing willingness for EBM within their organizations. Several respondents also suggested that EBM case studies and examples of successful implementation could help clarify EBM objectives and approaches. However, there is no single way to achieve EBM and experience suggests that success also depends on the locations, institutions, and the mix of people involved (McLeod and Leslie, 2009; Wondolleck and Yaffee, 2017). When asked in interviews whether they have seen progress toward EBM, responses ranged from perceptions of “we just haven’t gotten there yet” and “it is still an abstract,” to “tremendous strides.” We followed up asking what they perceived as the most critical to any observed successes. Respondents described the efforts of “a few smart, articulate people” and “policy entrepreneurs” that were able to build trusted partnerships. Respondents also described the benefits of good science, drawing from local knowledge and participation, and political backing for EBM actions.

CRITICAL AND EMERGING SCIENCE TO SUPPORT EBM ACROSS COASTAL REGIONS OF THE US

Our synthesis of the critical science needs to enable and enhance coastal EBM in the US is a high-level summary of the most common needs revealed through the regional analyses compiled for this report. The specific EBM needs relevant to a particular local or regional coastal system may be substantially different due to ecological differences as well as science, management, and governance history. However, throughout our analysis of the research needed to achieve the necessary understanding to support EBM, one commonality persisted. Successful EBM requires a commitment to interdisciplinary[3] research. Our analysis of the survey and interviews, bolstered by our review of strategy and planning documents, consistently indicated that the resources to develop and implement an interdisciplinary approach required of EBM are limiting. Respondents noted that this step is time consuming and has historically not often resulted in effective collaboration or consensus. A key barrier to interdisciplinarity in coastal EBM may be a lack of formal guidance on how to do interdisciplinary research (Alexander et al., 2019). An important factor is undoubtedly a shortage of committed resources and incentives (funding, time, and expertise) that makes the ecosystem approach difficult to initiate and sustain (McLeod and Leslie, 2009b; Fortnam, 2019).

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[3] We use the term *interdisciplinary* to broadly describe science that integrates the knowledge and procedures of multiple scientific disciplines because it is presently in common use. For example, the science may call upon several biophysical disciplines, though it more commonly refers to a combination of knowledge from both social and ecological systems. We acknowledge that similar terms, such as *multi-disciplinary* and *transdisciplinary,* can be used to describe the nuances of cross-boundary work and may also be appropriate labels for the research described here.

Ecosystem Science

According to EBM those who study and implement EBM, maintaining habitat and species diversity, balancing predator-prey interactions, and preserving ecosystem function and connectivity should form the scientific foundation of ecosystem-based strategies and inform the planning process (Foley et al., 2010). The holistic approach that characterizes EBM is necessary for effective management of coastal ecosystems because the connectivity that makes coastal ecosystems productive, and thus socio-economically and ecologically critical systems, is also what makes them vulnerable to the effects of change on land and at sea (Yáñez-Arancibia et al., 2011).

A major theme in the critical science needs for EBM expressed in the survey and other sources was the characterization of interconnected ecosystem processes. Such characterizations can be achieved through integrated biogeochemical research that examines cause and effect relationships, habitat and species resiliency, and feedbacks across the land-water system. Sources commonly acknowledged the need to understand cascading ecosystem effects resulting from stressors and management efforts. Frequently named science included the identification of critical ecosystem indicators and baseline system conditions since such tools and understanding underpin the ability to use monitoring and modeling to evaluate ecosystem change. Research characterizing human interactions with the system, such as multi-use conflict analyses of in-water activities, were suggested to support marine spatial planning and integrated coastal zone management that determine siting of infrastructure, protected areas, and other ocean uses. Integrated ecosystem science can encourage the development of robust strategies to simultaneously provide multiple benefits and reduce conflicts among ocean users, thereby removing impediments to implementing EBM (Katsanevakis et al., 2011; Ansong et al., 2017).

Perhaps the most pressing unknowns expressed were how and how quickly climate change will impact coastal and marine environments. Ecosystem science needs to anticipate the ecological effects of climate change appeared in survey responses from every region. Climate change is already altering coastal and ocean ecosystems and affecting ecosystem services (Pershing et al., 2018) and the cumulative or net effects of changing ecological processes remain uncertain (Rice, 2010). Moreover, as many of the connections between the watershed, estuary, and coastal ocean are mediated through physical-chemical processes, we can anticipate that these connections will be different under various climate change futures (Testa et al., 2018) and be modified by human responses and adaptations to change. A perception that emerged from some survey respondents and interviewees was that broadening biophysical research to reduce uncertainty is the key to improving the capacity of decision makers to confront climate change.

Themes for ecosystem science to enable or enhance EBM common across regions included:

Biogeochemical and ecological connectivity and ecosystem interactions, including new technologies for monitoring and assessment to characterize ecosystem structure and function, species interactions, and variables influencing energy transfer and productivity

Impacts of climate change on habitats and species resiliency, including describing the quantity and quality of existing habitats and forecasting shifts in species distribution, sensitive habitats, and resource availability

Impacts of anthropogenic activities and management actions on coastal ecosystems, including understanding the cumulative effects of coastal and marine development (e.g., aquaculture, offshore energy, shoreline change) on habitats and species, and monitoring and evaluating the effectiveness of management strategies (e.g., restoration projects, marine protected areas) to improve decision making and adaptive management

New technologies for addressing impacts of climate change to ensure sustainability and resilience, including green infrastructure and support for innovative strategies to adapt to changing ecosystem and resource availability

Note: The following tables present the regional needs (left columns) that informed our synthesis of the common needs appearing across regions (top row), as presented in this chapter. The check marks indicate where the regional needs and examples generally fit within the common needs category.

Common Needs for Ecosystem Science

Region	Need	Biogeochemical and ecological connectivity and ecosystem interactions	Impacts of climate change on habitats and species resiliency	Impacts of anthropogenic activities and management actions on coastal ecosystems	New technologies for addressing impacts of climate change to ensure sustainability and resilience
Northeast	Food web and ecosystem structure and function	✓			
	Wetland and nearshore habitats		✓	✓	✓
	Changing species behavior, distribution, and connectivity	✓	✓	✓	✓
Mid-Atlantic	Biogeochemical and ecological connectivity between watersheds and estuaries	✓		✓	✓
	Changes in habitats and productivities with climate change	✓	✓		✓
	New approaches to advance ecosystem modeling and habitat mapping	✓	✓		
	Emerging contaminants	✓		✓	
South Atlantic & Caribbean	Ecological connectivity between watersheds and nearshore ecosystems	✓		✓	
	Coral reef health and function	✓	✓	✓	
	Climate change impacts on coastal ecosystems		✓		✓
Gulf of Mexico	Ecosystem connectivity pathways and processes	✓	✓		
	Ecological responses to changing coastal habitats	✓	✓	✓	✓
	Ecosystem vulnerability to multiple ocean uses	✓		✓	

Common Needs for Ecosystem Science

Region	Need	Biogeochemical and ecological connectivity and ecosystem interactions	Impacts of climate change on habitats and species resiliency	Impacts of anthropogenic activities and management actions on coastal ecosystems	New technologies for addressing impacts of climate change to ensure sustainability and resilience
West Coast	Interactions at the land-sea interface	✓		✓	
	Impacts of climate change on habitats and ecosystem function	✓	✓		✓
	Analysis of coupled biophysical processes and habitat integrity	✓	✓		
	Ecosystem impacts from in-water anthropogenic activities	✓		✓	
US Pacific Islands	Coral reef health and resilience	✓	✓	✓	✓
	Climate change and land-use influences on habitat integrity	✓	✓	✓	✓
Alaska & US Arctic	Ecosystem connectivity	✓	✓	✓	
	Climate change impacts on coastal ecosystems	✓	✓		✓
Laurentian Great Lakes	Habitat and food web dynamics	✓	✓	✓	
	Pollutant cycling and impacts on ecosystems	✓			

Socio-Ecological Science

EBM is a framework for managing social-ecological systems rather than a singular approach to management (Leslie, 2018), typically envisioned as a stakeholder-driven process in which solutions to problems are jointly developed by communities, scientists, and governments. However, survey respondents frequently expressed the view that social science had been insufficiently applied to speed up or enable EBM implementation. In particular, science describing the socioeconomic impacts of management actions was among the most frequently suggested research to enhance EBM in several regions. Survey respondents wanted to know: How does a change in management strategy affect the system, and in turn, local or regional human well-being? Such research included identifying social implications of changes in ecosystem services beyond direct financial impacts and specifying which groups bear the costs and receive the benefits. Valuation of ecosystem services or monetizing benefits of a proposed change can be powerful tools when deciding which actions to undertake (by comparing costs to benefits) (Arkema et al., 2015) and some types of government funds are only available if net benefits have been demonstrated. However, merely providing values for ecosystem services does not necessarily motivate all the types of changes needed to achieve EBM goals. Therefore, understanding what incentives might help bring about the changes in human behavior that lessen or mitigate negative impacts to coastal resources is a distinct research need.

Another common and unifying theme that emerged from our analysis was the need for more comprehensive integration of sociocultural values into management decision making to promote equity and human community resilience. Highly interdisciplinary socio-ecological research is critical to developing indicators and models to assist managers in balance the multiple issues in marine ecosystems (Thébaud et al., 2017). Metrics that can reasonably characterize changes in both biophysical and socioeconomic outcomes can improve understanding and communication of the tradeoffs of management alternatives, inform risk assessments, and characterize vulnerable communities (Leslie and McLeod, 2007; Arkema et al., 2015; Gaichas et al., 2018). Integrated social-ecological models have the potential to test and understand assumptions about key drivers of change (Rice, 2010). However, there is an imbalance in monitoring of the social and biophysical characteristics needed to inform coastal resource management decision making (Christie, 2011). The development of integrated models that are able to capture local knowledge and values as well as quantitative relationships of major ecosystem metrics could help coordinate research with managers' needs and tailor models to managers' questions. Research into methods to select, measure, and project change in metrics as a result of management, is therefore part of the socio-ecological science need.

Themes for socio-ecological science for coastal EBM that occurred across our regional analyses included:

Socioeconomic evaluations of the effects of management actions, including cost-benefit analyses as well as monitoring and assessment of the ecological and social impacts of past and planned projects (e.g., hazard mitigation, managed water systems)

Strategies and tools to support prioritization and decision making for sustainability and resiliency, including developing integrated socio-ecological models and adaptive frameworks, social science (e.g., environmental sociology and psychology) to identify effective incentives, and tradeoff analyses to balance multiple ocean uses

Cost-benefit analyses of potential adaptation strategies, including conservation, restoration, retreat, and retrofitting

Methods to enhance environmental equity and inclusion in decision making, including identifying and integrating sociocultural values, recognizing unbalanced power structures, and characterizing social vulnerability to environmental change

Common Needs for Socio-Ecological Science

Region	Need	Socioeconomic evaluations of the effects of management actions	Strategies and tools to support prioritization and decision making for sustainability and resiliency	Cost-benefit analyses of potential adaptation strategies	Methods to enhance environmental equity and inclusion in decision making
Northeast	Offshore energy development and potential use conflicts	✓	✓	✓	
	Identification of social values and cultural ocean uses for integrated coastal planning		✓	✓	✓
Mid-Atlantic	Effects of ecosystem management actions on human well-being	✓		✓	✓
	Innovative solutions to reduce environmental impacts of coastal development		✓		
	Multi-use conflict analyses for in-water activities	✓	✓	✓	✓
	New methods to enhance communication and consensus building for ecosystem sustainability		✓		✓
South Atlantic & Caribbean	Socioeconomic structures of waterfront communities		✓		✓
	Effects of management actions on ecosystem health and human well-being	✓		✓	✓
	Recovery from catastrophic storms and adaptation to climate change impacts	✓	✓	✓	✓
Gulf of Mexico	Effects of catastrophic events and methods to enhance management response	✓	✓	✓	✓
	Socioeconomic impacts of restoration and conservation actions	✓			✓
	Coastal community adaptation to sea level rise	✓	✓	✓	✓

Common Needs for Socio-Ecological Science

Region	Need	Socioeconomic evaluations of the effects of management actions	Strategies and tools to support prioritization and decision making for sustainability and resiliency	Cost-benefit analyses of potential adaptation strategies	Methods to enhance environmental equity and inclusion in decision making
West Coast	Innovative solutions to design and achieve sustainability and resiliency goals		✓	✓	✓
	Tradeoff analyses and strategies to support prioritization and decision making	✓	✓	✓	✓
	Strategies to enhance inclusive coastal planning, equity, and environmental justice	✓	✓		✓
US Pacific Islands	Restoration and conservation prioritization and effectiveness	✓	✓	✓	✓
	Aquaculture feasibility for economic growth and food security	✓	✓	✓	✓
	Spatial tools and indicators to evaluate multiple ocean uses		✓		✓
	Co-development of science to improve the integration of traditional ocean uses into management		✓		✓
Alaska & US Arctic	Methods to understand and balance multiple ocean uses	✓	✓	✓	✓
	Effects of climate change on subsistence and traditional ocean uses		✓	✓	✓
Laurentian Great Lakes	Socioeconomic analyses to support prioritization for restoration and conservation projects	✓	✓	✓	✓
	Human health effects of pollutants		✓		✓
	Nutrient management effectiveness and innovation	✓	✓	✓	

Governance and Incentives

In many situations, EBM is no longer substantially limited by of a lack of conceptual understanding or by the unwillingness of resource managers, but more by questions of *how* to put it into practice given the multitude and complexity of place-based issues and existing governance practices (Marshak et al., 2017; Link et al., 2019). Issues related to applying science to management needs and insufficiently flexible governance frameworks were consistently mentioned in the survey, interviews, and informal discussions with coastal managers and marine scientists. We created the research category of *Governance and Incentives*, to reflect common EBM community concerns and to highlight that institutional structure and effectiveness is an interdisciplinary science, but is often less familiar than the more conventional biophysical and socioeconomic sciences.

EBM implementation is an iterative process (Samhouri et al., 2014) in which practitioners must consider existing management and institutional structures and make an explicit decision whether to work within the prevailing regime or with an intent to incrementally shift toward something else (Leslie et al., 2015). EBM has been called a "revolutionary" process of governance where cooperative partnerships, co-production of knowledge, and social learning steer multiple disciplines toward sustainability of marine ecosystems (Berkes, 2012). Yet some stakeholders continue to be marginalized and not equally integrated into decision processes. Research into inclusive and equitable governance structures and processes was identified across regions.

According to survey respondents, major challenges to coastal EBM implementation arise from limitations created by insufficient commitments toward transforming institutions to work within the EBM framework (Crowder et al., 2006; Frazão Santos et al., 2018; Fortnam, 2019). A lack of willingness to apply resources or change existing practices to enable EBM were commonly reflected in the survey. Research can improve understanding of the most critical institutional barriers and recommend approaches to overcome resistance to transformation (Fortnam, 2019). We recognized a persistent need to incentivize and expand integrated research capacity to characterize links between human and ecological systems with the goals of maintaining key elements of ecosystem resilience (e.g., diversity, ecological connectivity) and open options for management adaptation (Leslie and Kinzig, 2009; McLeod and Leslie, 2009b). Further, institutional innovation has been identified as a means to enhance knowledge exchange among coastal scientists and policy makers (Cvitanovic et al., 2015), which many respondents felt was needed to achieve more effective coastal management.

These suggestions support a more general strategy to encourage governance for coastal resiliency by reframing the EBM narrative into terms that resonate with human decision making and provide incentives for action (Wainger and Boyd, 2009; Mumby et al., 2017). As an example, economists often suggest that an effective way to change behavior, in ways that balance competing needs among user groups, is to create appropriate incentives through price signals, fees, payments, and/or social rewards. These approaches are predicated on the idea that individuals or entities are typically making optimal decisions from their perspectives, even if those individual actions result in an outcome that is less than optimal from a whole system perspective. As a result, the goal of economic incentives is to change the calculus of what is optimal from a given decision maker's perspective. Economics (and social scientists from other fields such as law, policy analysis, and institutional behavior) conduct research regarding the specific incentives, laws, or policies that are likely to be effective and legally permissible to change outcomes, given how individuals or entities make decisions.

Common needs identified for governance and incentives to support EBM were:

> **Methods to improve the accessibility and relevance of science to resource managers' needs and objectives,** including strategies for co-development of knowledge and frameworks to support development of interdisciplinary science and coordination among agencies and industry to achieve multi-faceted management goals
>
> ***Development of detailed guidance and approaches for implementing EBM,*** including case studies and examples of effective EBM and integrated management techniques, lessons learned, pilot programs
>
> ***Innovative management structures for building cooperative initiatives,*** including evaluating institutional barriers to EBM and simplifying procedures to enable and improve communication, coordination, and goal setting among agencies
>
> **Resilience science to enhance coastal planning,** including characterizing ecological resilience links to human well-being, and climate change vulnerability of ecosystems and human communities

Common Needs for Governance & Incentives

Region	Need	Methods to improve accessibility and application of science to management needs	Development of detailed guidance and approaches for implementing EBM	Innovative management structures for building cooperative initiatives	Resilience Science to Enhance Coastal Planning
Northeast	Enhanced communication and consensus building	✓		✓	✓
	Cost-effective techniques for ecosystem assessment and monitoring	✓	✓		
	Integrated management techniques for fisheries and aquaculture		✓	✓	
Mid-Atlantic	Strategies for integrating science and management objectives	✓	✓		✓
	EBM Effectiveness and implementation progress		✓		
	Cost-benefit analyses of potential methods of adaptation to climate change for coastal communities		✓	✓	✓
South Atlantic & Caribbean	New methods to enhance communication and consensus building to achieve shared goals for sustainability and resilience	✓	✓	✓	✓
	Strategies for integrating ecosystem-level science and management objectives	✓	✓		✓
Gulf of Mexico	Strategies to support systems-level perspectives in fisheries management		✓	✓	
	Ecological resilience links to human community well-being	✓		✓	✓

Common Needs for Governance & Incentives

Region	Need	Methods to improve accessibility and application of science to management needs	Development of detailed guidance and approaches for implementing EBM	Innovative management structures for building cooperative initiatives	Resilience Science to Enhance Coastal Planning
West Coast	Management interventions for sensitive and endangered species		✓	✓	
	Strategies to achieve greater sustainability in fisheries and aquaculture	✓		✓	✓
US Pacific Islands	Invasive and nuisance species management approaches		✓	✓	✓
	Integrated fisheries management and links to ocean livelihoods	✓	✓	✓	
	Management structures and planning for sustainable and resilient communities		✓	✓	✓
Alaska & US Arctic	Cooperative management strategies for sustainability and equity	✓		✓	✓
Laurentian Great Lakes	Tools to improve lake level management strategies	✓		✓	
	Shoreline resiliency planning	✓	✓	✓	✓

Tools Needed to Enhance EBM Capacity

Certain quantitative tools and issues related to data and modeling were repeatedly mentioned across regions. Many of the experiences described by respondents revealed the need for better integration of datasets and databases to enable confident use of the diverse data. Data challenges included the need to merge different sources of historical data with new data, including those gathered via remote sensing and data from other emerging technologies. Such integrated databases provide the basis for analyses and modeling that span many dimensions (economics, biology, people) and can address the heterogeneity across temporal and spatial scales. A related need that was commonly identified was continued and additional support of monitoring to allow for assessment of EBM actions across scales relevant to the ecosystem, management, and people. Monitoring that is well matched to management indicators can enable trends and outcomes of actions to be meaningfully interpreted by decision makers and encourage adaptive management strategies.

Coupled biophysical and social modeling is rapidly advancing, and models that explicitly link (with appropriate feedbacks) the biology with the dynamics of physical, climatic, ecological, economic, and social systems would aid in analyzing coupled human-natural systems that underlie much of EBM and in creating transparent decision-support methods (see, for example, reviews bu Kareiva et al., 2011 and Schlüter et al., 2012). Further research could improve and streamline application of process-based or empirical models and other analytic tools that can assess cumulative impacts, socioeconomic effects, tradeoffs among stakeholder goals, and restoration cost-effectiveness, among other uses. Efforts are needed to ensure that new tools and models are available and useable, and are clearly documented on their uses, weaknesses, and strengths. Targeted modeling may be needed to tailor tools to the needs of EBM applications. Access to climate projections with known certainties and easily accessible projection data usable at multiple scales for input to other analyses (EBM-related) are required for most all EBM implementations. Therefore, efforts to make climatic projection data accessible can reduce the time needed to include climatic effects in models and tools.

Finally, further development of approaches and tools for the co-development of science and management goals and for effective communication across institutional units (e.g., agencies, disciplines) and for engagement of stakeholders would enhance many EBM implementations. Communication tools are needed in order to ensure efficiency, accountability, and transparency and to build trust among groups.

The need for a dialog – an EBFM example

Ecosystem-based fisheries management (EBFM) is generally considered a subset of EBM. EBFM was once perceived as too complex and vaguely defined to be realistically implemented, but recent progress using ecosystem assessments, fisheries reference points, and other decision tools to support EBFM (Patrick and Link, 2015; Dolan et al., 2016; Link et al., 2020) could provide lessons for achieving ecosystem-based objectives in the broader sense of EBM.

> *"Perhaps the greatest dilemma faced by most [marine EBM] initiatives was determining their relationship to fisheries management."*
>
> (Wondolleck and Yaffee, 2017)

We expected to see the subject of fisheries in survey responses, as regional EBFM is an existing effort across the US, and we did not explicitly list fisheries in the survey to encourage other less prevalent issues. However, through our process we experienced sources using the terms EBM and EBFM almost interchangeably. We recognized that, while there are some distinct institutional roles at play, the success of EBM is inextricably interwoven with the processes of EBFM and thus a critical area for improved communication and coordination – one of the most common needs revealed in our analysis.

Recently, debates around the implementation of ecosystem reference points for Atlantic menhaden have revealed a challenge that both fisheries management and the broader ecosystem management process must address. Fishery managers were uncomfortable setting a target for management and turned to fishery scientists for guidance. The scientists had provided clear, measurable advice on setting thresholds, so why could they not provide advice on targets? Fishery scientists were comfortable providing advice in the objective and value-neutral domain of not exceeding thresholds, but were uncomfortable telling managers what they should want as a target. These same scientists recognized that the aspects that should be considered for setting a target went beyond these objective factors. For almost a year, managers asked scientists to suggest a target and scientists pushed back, saying "we can give the exploitation rate if you tell us what it is trying to achieve." There was good will on both sides, but a failure to recognize the important distinction in each other's role.

The impasse was broken with a modeling tool that the scientists developed that allowed managers to understand the consequence of the alternative targets that they could envision. The tool allowed them to explore the response of the system to different interpretations of what was important – of what was valued.

EBM will face this same dialogue. It is much easier to define combinations that are not sustainable. It is much harder to choose among the various combinations that are sustainable, some of which will not be desirable. But not desirable to whom?

Some Common Observations

Our study and analyses confirmed many of the issues and opportunities available for furthering the effective implementation of EBM identified in earlier analyses and from other ecosystems. Many of the examples used to illustrate the critical science needs by region, when viewed generally, revealed some commonalities, while also demonstrating the importance of a local context for EBM. When one looks at the vast accumulated information and knowledge base on EBM and combines this with our targeted survey and interview results, some general observations emerged. Note that these observations were based on a non-statistical survey design and on literature mostly devoted to EBM, and thus may not apply to broader populations of scientists, managers, and policy makers.

- There is significant appreciation of the value of EBM among scientists and coastal resource managers.
- In many regions (not all), the present foundation of science at local and regional scales can, with varying degrees of augmentation, support the implementation of EBM.
- Many critical science needs are common across regions, and some common approaches could be used to make them relevant at appropriate scales, among and within regions.
- Strong consideration of the human dimensions of ecosystems is necessary for effective implementation of EBM in practically all situations identified.
- Socio-ecological science, governance, and institutional considerations, in combination with focused research on critical ecosystem science needs, provides an implementable path forward for furthering effective design and maintenance of EBM.
- Additional development of integrated databases, tools, and models would enhance EBM across regions and be leveraged for their use in many specific EBM situations.

All indications are that the desire, use, and demand for EBM approaches will continue to accelerate for coastal systems. This report builds upon, expands, and updates the 2008 Prospectus and offers many candidate problems and locations where targeted science can enhance the implementation of EBM.

Critical and Emerging Science to Support Ecosystem-Based Management

Northeast

Ecosystem Science

- Food web and ecosystem structure and function
- Changing species behavior, distribution, and connectivity
- Wetland and nearshore habitats

Socio-Ecological Science

- Identification of social values and cultural ocean uses for integrated coastal planning
- Offshore energy development and potential use conflicts

Governance and Incentives

- Integrated management techniques for fisheries and aquaculture
- Cost-effective techniques for ecosystem assessment and monitoring
- Enhanced communication and consensus building

Northeast

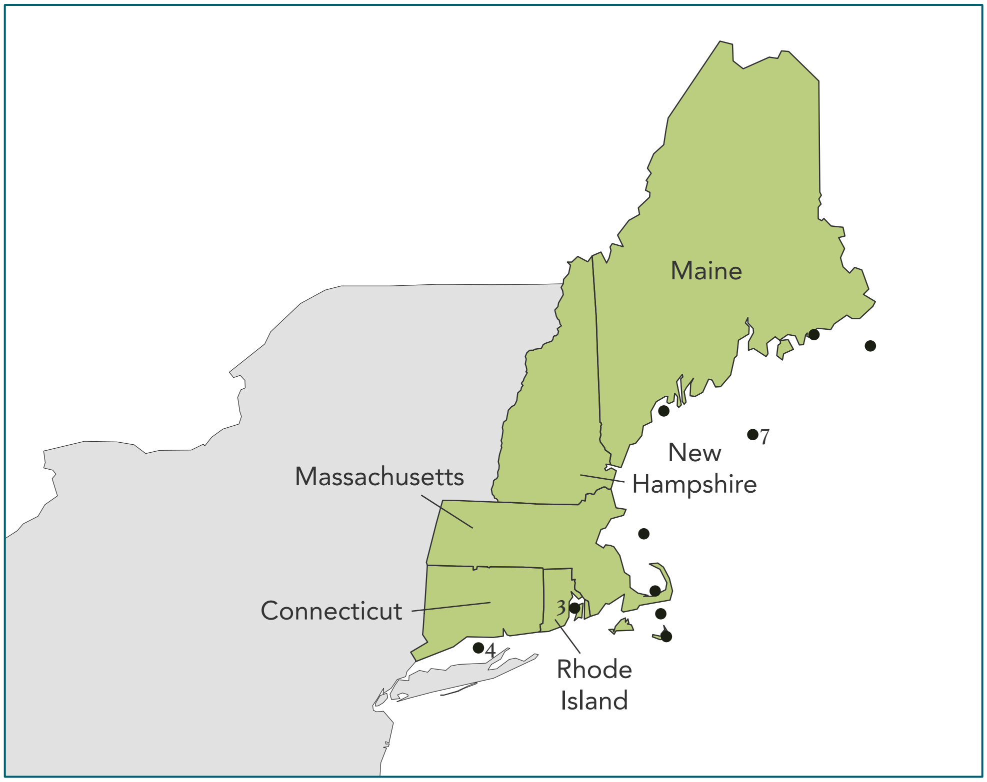


Figure 5. Northeast region and locations described in surveys and interviews. Numerals indicate locations described by more than one respondent.

The US Northeast region described herein is bordered on the west by the coastlines of Maine, New Hampshire, Massachusetts, Connecticut, and Rhode Island. Bays, inlets, and islands are prevalent coastal features of region. The marine region includes the Gulf of Maine, a semi-enclosed sea, and the shallower ecosystems of the Scotian Shelf and Georges Bank within the productive and complex northern Atlantic Ocean.

Features of EBM in the Northeast

Coastal EBM in the Northeast region has been implemented to some degree since at least the early 2000s, and arguably much longer, if activities with similar goals but different names are considered (Wondolleck and Yaffee, 2017). For example, the Gulf of Maine Council on the Marine Environment between the US and Canada was established in 1989 to support ecosystem-level management to maintain environmental health and community well-being across geopolitical boundaries. Since the northern Atlantic coast and ocean is shared between nations, a broad ecosystem view was applied to facilitate cooperation.

Several evaluations of the needs to implement EBM in the Northeast region were completed in the late 2000s (e.g., NOAA National Centers for Coastal Ocean Science 2008, Taylor 2008, MRAG Americas et al. 2009). Those working on EBM issues in the Gulf of Maine in 2007 were most interested in habitat assessment and restoration and sought information about ecosystem function, anthropogenic influences, and projections of future change to inform management (Taylor, 2008). In Massachusetts, recommendations included indicator and model development, assessment of habitat health and vulnerability, and evaluation of ecosystem services (MRAG Americas et al., 2009).

The Northeast Ocean Plan (Northeast Regional Planning Body, 2017) explicitly prioritized an EBM approach to managing New England's coastal area. It is a comprehensive evaluation of the Northeast region's ocean resources, planning priorities, and knowledge gaps prepared in cooperation with numerous state, tribal, and federal agencies to guide regional ocean planning, although it is not legally binding. Likewise, EBM is a stated goal of the Massachusetts Ocean Management Plan (Massachusetts Department of Environmental Protection, 2015). Ecosystem-based fisheries management (EBFM) in the region, which could be considered a subsection of EBM, has also made progress in integrating climate, habitat, and human dimensions into reports, assessments, and research goals. NOAA's Northeast Fisheries Science Center has been producing annual State of the Ecosystem reports since 2017. The New England Fisheries Council is considering restructuring its management program to better develop EBFM polices (NOAA Fisheries, 2019f).

Perceptions of EBM in the Northeast

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Northeast region, we received 27 survey responses and conducted follow-up interviews with four of these participants. Survey respondents self-identified their roles (Table 1A) and we identified the level of organizational affiliation from the email addresses provided in survey responses (Table 1B).

Table 1. Self-identified work titles (A) for Northeast respondents and organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	10
Scientist & Resource manager	3
Resource manager & Policy maker	1
Resource manager only	4
Policy maker only	2
Scientist & Policy maker	1
Did not identify as above	6
Total	**27**

B.

Organization	
Federal government	4
State government	3
Non-governmental organization	3
University	5
Unidentified	12
Total	**27**

All 27 survey participants agreed that EBM was a goal in their work and that they provide guidance for management decisions. Nineteen respondents agreed that EBM was currently being used, and the remaining 8 responded that it was not yet being used in their work.

The general priorities and views of respondents in the Northeast region showed some similar patterns as in other regions. The majority of respondents indicated that there were important science and communication needs that, if met, would enhance the likelihood of successful EBM implementation in the region (Figure 6). The Northeast can perhaps be considered among the US regions with consistent consideration of EBM in planning and strategy documents. However, only 11% of survey respondents describing Northeast locations perceived successful implementation of EBM (Figure 6). This suggests there are many opportunities where additional targeted research could further enhance the effectiveness of EBM strategies.

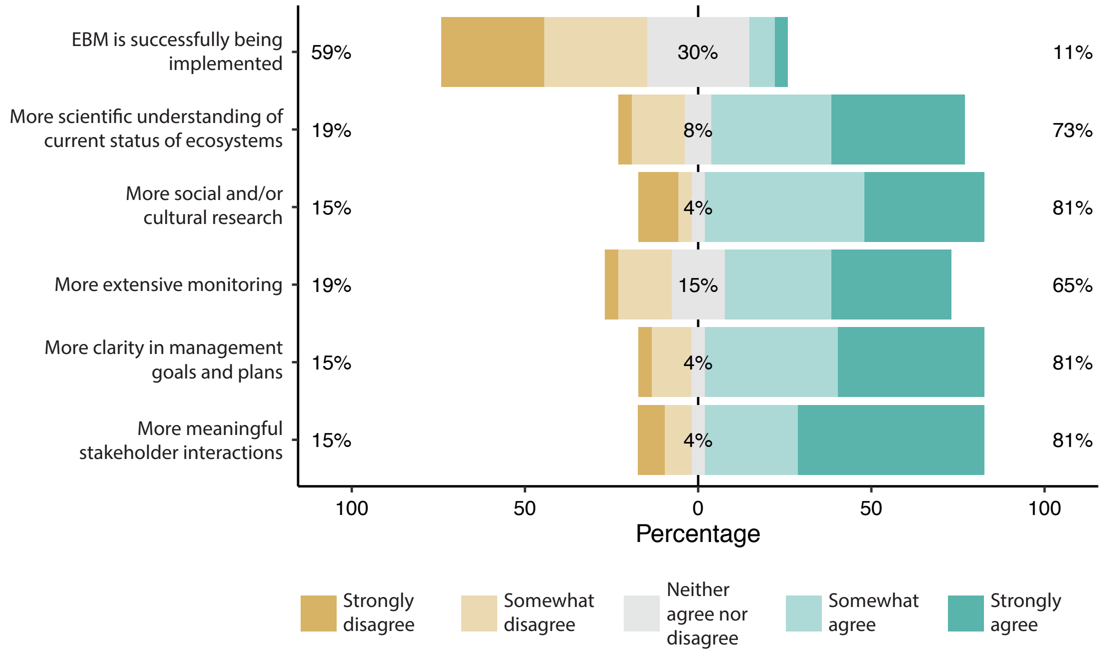


Figure 6. Practitioner opinions on needs before fully implementing EBM in locations in the Northeast region (SQ12, n=27). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad environmental and socioeconomic issues in locations in the Northeast region, respondents commonly acknowledged the importance of *water quality*, *habitat integrity*, and *coastal resilience* (Figure 7). Each of these issues was rated very or extremely important by greater than 85% of respondents. In the 14 write-in responses listing additional issues that were very or extremely important for a location, fisheries issues were listed in half of the fill-in responses and were by far the most common addition. We expected to see the subject of fisheries in these responses as EBFM is an existing and prominent effort in the Northeast. Therefore, we did not explicitly list fisheries in the survey to encourage other less prevalent issues. Results of our analysis for multiple regions, including the Northeast, suggested that fisheries were regarded by many respondents as a distinct environmental concern within EBM.

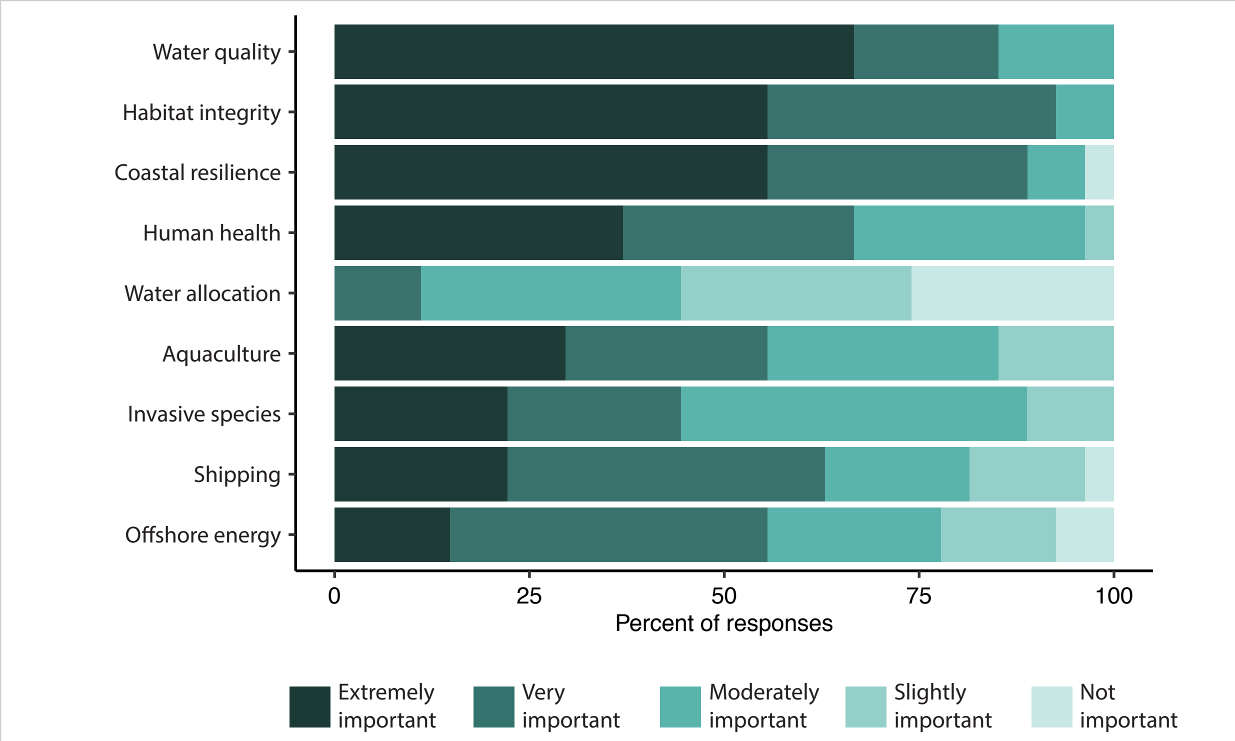


Figure 7. Priority issues as described by online survey respondents (SQ7, n=27).

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). Seventy percent of Northeast respondents selected *implementing an interdisciplinary approach* as the most difficult aspect of EBM to achieve (Figure 8). It is noteworthy that such a strong response came from a region with a history of EBM-like activities. One interviewed scientist and policy maker described interdisciplinarity as "perpetually daunting but incredibly important." *Interpreting healthy, productive, and resilient ecosystems* was regarded as the easiest EBM aspect to achieve by half of respondents, suggesting that practitioners have a good understanding of desired ecosystem states.

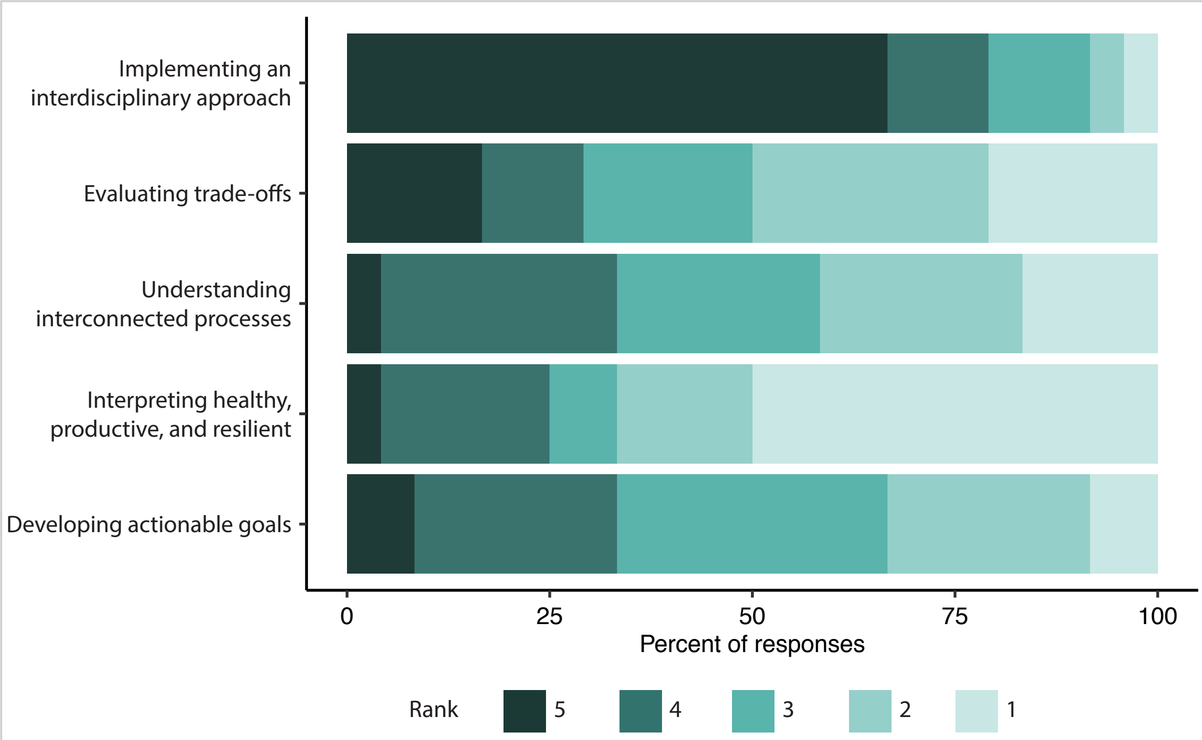


Figure 8. Perceived relative difficulty of EBM attributes, where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=24).

When asked to rate the influence on EBM (either supporting or hindering) of a list of management characteristics, all but one of the items in the institutional and management capability categories were said to be hindering (strongly or somewhat) EBM implementation by greater than half of respondents (Figure 9). Although the majority of survey respondents agreed that more science is needed before fully achieving EBM (Figure 6), the existing *monitoring*, *data availability*, and *understanding of ecological linkages* were considered by greater than 50% of respondents as sufficient to support EBM planning and implementation (Figure 9).

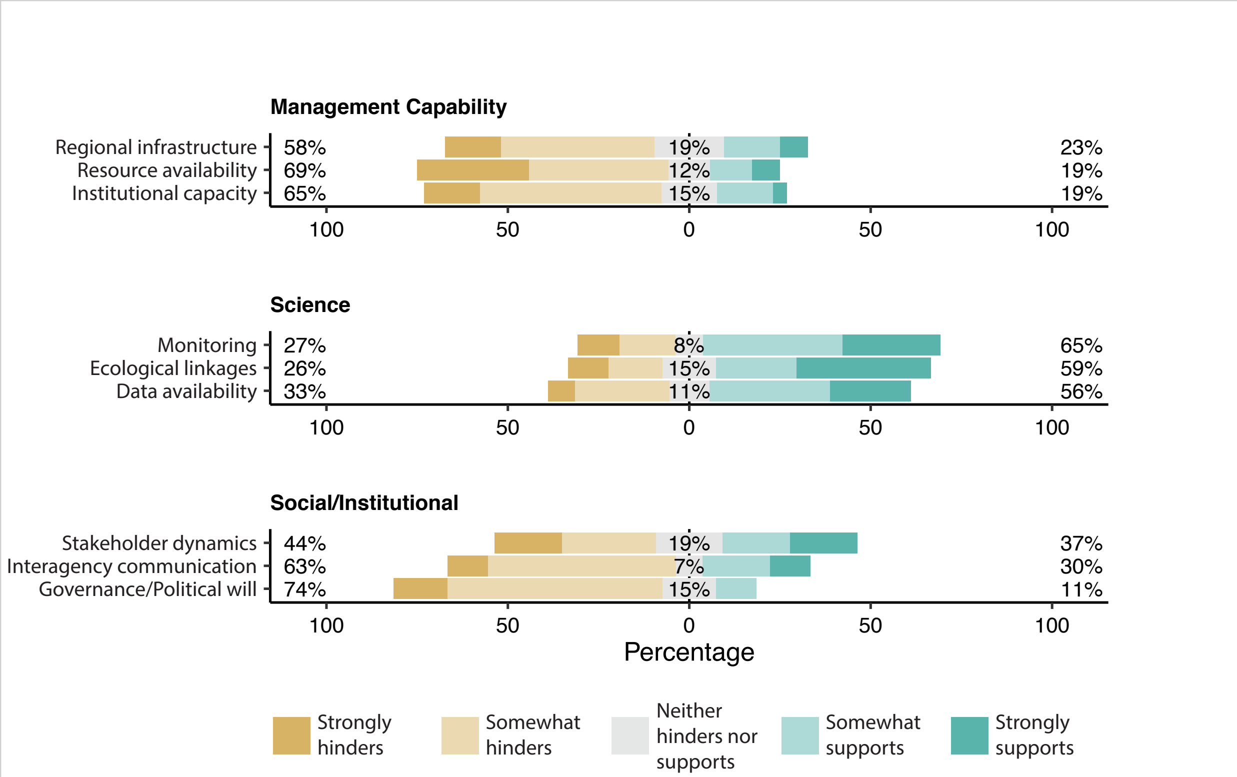


Figure 9. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11, n=27).

Responses to the question, *What is the biggest non-science barrier to EBM?* commonly described challenges associated with stakeholder buy-in and implementation within existing institutional structures, as coded in eight and seven of the 26 write-in responses, respectively (Figure 10). Participants perceived limitations to EBM in current management authority structures (e.g., permitting, coordination across agencies) and a lack of stakeholder trust that these changes would work to their benefit. The results for the Northeast confirm a broad issue that successful implementation of EBM relies on the feasibility of institutional structures to smoothly accommodate and communicate EBM activities.

Figure 10. Coded themes of responses describing non-science barriers to EBM (SQ42, n=26) in the Northeast region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. Responses generally covered the large range of issues that would be expected for the complex and productive Northeast region. Habitat value and assessment was the most common general theme in responses to the inquiry in the Northeast, described in more than one third of survey responses (Figure 11). Climate change followed in frequency, with eight of 25 comments, focused primarily on ecosystem response and socioeconomic effects of sea level rise. Fisheries, food web, and social-ecological connections were each discussed in five of 25 survey responses for science needs important to EBM in the Northeast.

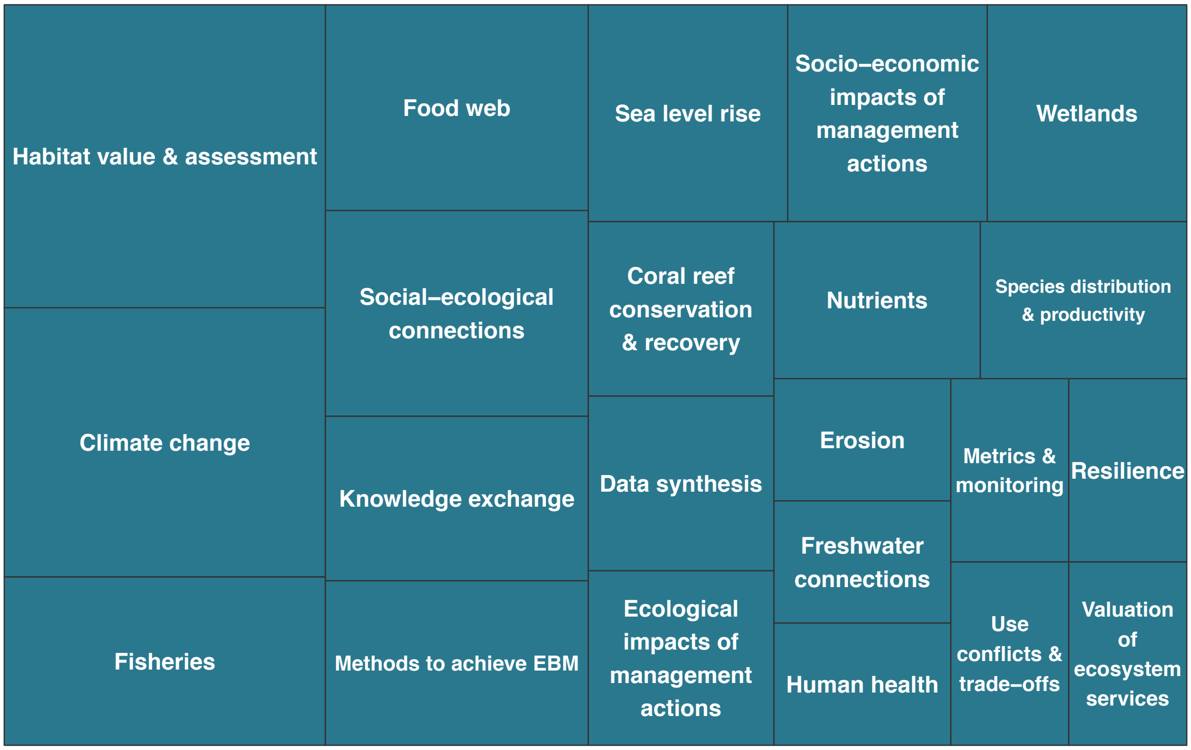


Figure 11. Topics appearing more than once in survey responses describing critical science needs for EBM in the Northeast (SQ10, n=25). Larger boxes correspond to more frequent mentions.

Critical and Emerging Science to Support EBM in the Northeast Region

One of the purposes of this project was to provide an update to the 2008 Prospectus (NOAA National Centers for Coastal Ocean Science 2008), a document that has helped guide regional coastal science research to address EBM and other management needs. Broad research priorities for the Northeast presented in the 2008 Prospectus included understanding multiple impacts to aquatic ecosystems and coastal communities (e.g., from climate change, energy exploration, development, land use, transportation) and ways to mitigate these impacts. The guide further suggested that EBM would benefit from the development and refinement of analytic tools and models that could be used to synthesize science for decision making. There was a focus in the 2008 Prospectus toward coupled physical and biological models. This effort updates and expands upon those recommendations.

Ecosystem Science

Survey responses and regional management plans and reports described a need for additional science on species, food webs, and habitats of the Northeast. Such ecosystem science included the characterization of Northeast coastal habitats and would provide the capability to anticipate resilience to the effects of anthropogenic activities and climate change. For example, advanced understanding of ecosystem processes is needed to better identify ecosystem-level vulnerability and risk (NOAA Fisheries, 2019f). The 2008 Prospectus identified the need for coupled physical and biological models to predict food web and ecosystem change. A similar priority was expressed in recent regional planning documents encouraging forecasting models to support decision making (e.g., National Ocean Council 2017, NOAA Fisheries 2019). The examples of this new science described in surveys and interviews, though not explicitly described by respondents for the goal of modeling, would also support model development and testing.

> "It's a changing food web – from the perspective of the whole ecosystem, how is it responding?"
>
> -Responding Scientist

Habitat integrity was rated as very or extremely important by greater than 90% of survey respondents and examples of critical science offered by the respondents concerning habitat valuation assessment were the most common examples among coded themes. Identifying and mapping habitats and evaluating habitat vulnerability were also common priorities expressed in regional management plans (e.g., Massachusetts Department of Environmental Protection 2015, Northeast Regional Planning Body 2017, Connecticut Department of Energy and Environmental Protection 2019). The topics that emerged from the responses to our survey often had a link to research to describe habitat use and understand ecological responses to habitat change.

ES 1. Food web and ecosystem structure and function

Survey responses to the inquiry, *List the critical scientific information still needed to support or enable EBM* (Appendix B, SQ10) in locations in the Northeast spanned a range of subjects, but a majority of respondents' suggestions included aspects of increased understanding of food web and ecosystem structure and function. Regional plans also prioritized research within this topic, such as characterizing cumulative impacts of ocean uses and ecological changes on ecosystem services (Northeast Regional Planning Body, 2017), and acknowledged a need to generally advance understanding of food web and ecosystem processes (NOAA Fisheries, 2019f).

Survey responses, interviewees, and regional plans also described research needs to better understand how habitat change (from anthropogenic uses and climate change) and restoration actions affect species and food webs. For example, one scientist suggested "inadequate understanding" of nutrient enrichment impacts on production in benthic environments and the potential for cascading effects on the food web. Another scientist, working in the Gulf of Maine, suggested a need for new technology for studying the food web to make sure that restoration is having the intended effects, like effectively targeting the desired fish species.

The following examples of research within this category emerged from our analysis:

- Identifying changes in local and regional physical oceanography on decadal scales and under anticipated future conditions that will affect the structure and energetics of the associated food webs
- Role of shallow-water estuaries and habitats on overall productivity of their local ecosystems and their cumulative effects and connections to broader coastal ecosystems
- Quantitative and qualitative approaches for assessing the cumulative impacts of diverse activities on shared natural resources and integration and scaling of these impacts from individuals to ecologically-relevant outcomes (population to ecosystem)
- More explicit integration of habitat considerations into projections of how habitat loss and restoration affect food web productivity and stability, including the responses of ecologically and commercially important species
- Assessment of how shifts in the food web affect the overall productivity and dynamics of specific components (biogeochemistry, populations) of the food web

ES 2. Changing species behavior, distribution, and connectivity

Many survey responses describing critical science needs within four of the five most common themes (habitat value and assessment, climate change, fisheries, and food web; Figure 11) were interrelated within this topic of science to describe and predict species behavior and distribution in response to changing habitats. This same concern was common throughout regional strategy and planning documents. For example, research on habitat change is needed to inform and improve conservation and management (Woods Hole Sea Grant, 2019). There is also a need to fill gaps in survey coverage to better describe species distribution and movement (Northeast Regional Planning Body, 2017). There is still a lack of understanding of how climate change will further impact marine life and habitats (McCann et al., 2013; Northeast Regional Planning Body, 2017), but declines in economically important fisheries and disruptions in species interactions are expected (Horton et al., 2014). It appeared that the need for development of coupled physical and biological models to predict ecosystem change described in the 2008 Prospectus still exists in the Northeast region.

The following are examples of research that will support improved characterization of the interconnections of species in coastal ecosystems of the Northeast:

- Shifting migration and species distributions on seasonal, inter-annual, and decadal scales as a result of historical and anticipated future changes in physical transport and movement behavior during lifecycles
- Effects of climate change on the physiological health (e.g., allocation of energy to reproduction) of individuals for species already at their southern range limits
- Use of the multiple data sources, from climate to organisms, for integrated analysis of population, species, and community status and trends and their dependence on changing environmental and habitat conditions
- Evaluation of the ecological effects of invasive species and possible management actions for their mitigation (e.g., harvest green crabs)
- Advanced monitoring of the transport and movement responses, and resulting physiological effects, of key organisms that indirectly (e.g., forage) or directly (e.g., lobster) support economically important fisheries
- Quantification of how ocean acidification (combining laboratory and field) will affect the ecological performance of shell-forming organisms to enable acidification effects to be expressed with ecologically-relevant end points

ES 3. Wetland and nearshore habitats

Survey responses suggested critical research needs related to wetlands and nearshore habitat to further develop quantitative tools to enable prioritization of restoration initiatives and improve the ecological effectiveness of restoration actions. Nearshore habitats are particularly vulnerable in the Northeast where development has constrained inland migration with sea level rise. Some wetlands in the Northeast could experience permanent inundation (Horton et al., 2014). Surveys and regional planning documents also expressed critical science needs to evaluate the sensitivity of estuarine habitats to climate change and land use and to evaluate the effectiveness of mitigation strategies (e.g., New Hampshire Sea Grant 2019, NOAA Fisheries 2019).

Illustrative examples of science needs for wetland and nearshore habitats identified in surveys and planning documents were:

- Projections and contributing factors that affect salt marsh migration and dieback, and evaluation of the potential for management actions to promote restoration and maintenance of healthy marshes
- Projected wetland loss and identification of conservation potential to preserve wetlands for migratory birds, effective shelf-nursery area connections for estuarine-dependent species, and other ecosystem services
- New measurement techniques and modeling for identifying and quantifying the habitat quality and quantity (including connectivity) provided by multiple habitats that vary on relatively fine spatial scales in many estuarine and nearshore environments
- Innovative techniques for wetland restoration and data collection and modeling to enable projection of the anticipated time-scales of ecosystem services responses in restored habitats.

Socio-Ecological Science

Objectives identified for the region included identifying the links between human and environmental health (Gulf of Maine Council on the Marine Environment, 2018), developing and tracking metrics of community health and well-being in response to management (NOAA Fisheries, 2019f), and improving cost-effectiveness of methods to restore ecosystem services (New Hampshire Sea Grant, 2019).

Improving the connection between social and ecological sciences, which also involves improving each of them, was an often-stated issue in survey responses and follow-up interviews. For example, new research was identified to explore the interactions between human uses and habitat quality and quantity in order to forward the goal of co-locating multiple uses while minimizing conflicts (Northeast Regional Planning Body, 2017). One interviewed policy maker and scientist stressed that a more widespread institutional appreciation of the value of a broad approach with multiple disciplines working on the same issue is required before pursuing the socio-ecological science that is needed to achieve EBM. The respondent commented that institutions acknowledge the need to understand the human component, but are not making the investment to staff social scientists, noting that, instead, the "biological scientists [are] trying to do social science."

SES 1. Identification of social values and cultural ocean uses for integrated coastal planning

New research is needed to identify cultural and historic resources in the Northeast and to determine the potential impacts of coastal management decisions on these resources (Northeast Regional Planning Body, 2017). Regional plans and strategy documents included priorities for methods to identify and preserve maritime heritage, Native American cultural sites, and archaeological landscapes (Massachusetts Department of Environmental Protection, 2015; Maine Sea Grant, 2017; Northeast Regional Planning Body, 2017; Connecticut Department of Energy and Environmental Protection, 2019). Survey responses also expressed interests in identifying changes in the "social fabric" of Downeast fishers, who are losing access to the coast, and to better understand local socioeconomic structures to improve communication of the benefits of an EBM approach.

The following examples of socio-ecological research were developed from survey responses, interviews, and the various regional documents:

- Accounting for changes in non-market values of ocean resources and recreational and cultural uses
- Identification and characterization of cultural resources at risk from anthropogenic activities and climate change (e.g., related to coastal community ways of life, socio-demographic impacts, economic changes, adaptation potential)
- Methods to improve integration of the priorities of underserved and rural communities in regional and local planning and safeguard access to subsistence/small-scale fishing and cultural resources

SES 2. Offshore energy development and potential use conflicts

Survey responses and regional literature noted critical science needs for assessing the environmental and cultural resources of the Northeast and for identifying and understanding potential impacts from offshore energy development in order to inform permitting and other regulatory decisions. For example, survey respondents suggested there were important unknowns regarding the effects of electromagnetic fields from wind turbines on wildlife and humans, or how tidal power infrastructure might influence benthic ecological processes. Similar needs to manage use conflicts or co-produce benefits were identified in regional plans, with interests including the potential for co-locating offshore energy infrastructure with aquaculture (McCann et al., 2013) and effective approaches for mitigating the vulnerability of marine resources to offshore energy development (Northeast Regional Planning Body, 2017).

More generally, consistent elucidation of the tradeoffs associated with large scale offshore energy development in the Northeast is limited (Leslie, 2015; Petruny-Parker et al., 2015). The US Bureau of Ocean Energy Management's Intergovernmental Renewable Energy Task Force for the Gulf of Maine met for the first time in December of 2019 and emphasized more timely progress in offshore wind development. Participants in the meeting expressed the need for science (including experimental technologies) and impact evaluations to minimize or avoid negative effects on wildlife and commercial fisheries (BOEM, 2019). Some regional planning documents have also expressed the need for science that could assist managers in balancing the economic opportunities presented by offshore energy development with the potential socio-ecological effects (Cape Cod Commission, 2011; McCann et al., 2013). A common element appearing in many of these sources was urgency for

Watching the Whales

The water off the coast of New England hosts five species of endangered whales: fin, sei, sperm, the critically endangered right whale (only about 400 individuals remain), and the occasional blue whale. Several other protected whale species also frequent the region. Vessel strikes and entanglement in fishing gear are the most significant dangers for whales in the Northeast. Seasonal vessel speed restrictions apply in critical habitat areas of Massachusetts and voluntary precautions are encouraged near busy shipping areas. A few programs exist to help prevent harmful whale interactions (e.g., acoustic sensors that tell ships when whales are nearby, specialized fishing gear), but these tools have not been broadly adopted in the region. Innovative technologies for avoiding whale mortality by anthropogenic interactions are needed. But direct contact mortality is not the only concern for the region's whales. For example, managers want to know how wind farms will influence acoustic or physical habitats of whales? Changing habitats and ranges for food species, created by climate change, are also a threat. Potential changes in whale behavior and habitat use, and impacts on already threatened populations are still unknown. Science is needed to identify critical habitat and threats to endangered whales. Comprehensive, ecosystem-wide evaluation is essential for assessing recovery efforts for whales in the Atlantic.

Sources: Massachusetts Department of Environmental Protection 2015, Kraus et al. 2016, NOAA Fisheries 2019, 2020, Georgiou 2020.

decision making and responsible offshore wind development to address energy and sustainability needs of the region.

The following are broad examples of critical science needed to support EBM planning for permitting and siting offshore energy development:

- Evaluation of renewable energy options (e.g., offshore wind, tidal power) and potential impacts on ecologically important species and habitats to support siting and prioritization
- Socioeconomic benefits and ecological tradeoffs associated with offshore energy development (e.g., are increased energy costs due to moving equipment farther offshore offset by the public benefits of that change?)
- Development of models and tools to examine the cumulative impacts of large-scale or multiple, adjacent wind farms on ecosystems and fisheries
- Understanding of aesthetic concerns and mitigation options (e.g., visual impacts, design and placement of wind turbines that may make them more acceptable)

Governance and Incentives

Further implementation of EBM in the Northeast, like in other regions, must navigate the complicated collection of ocean governance structures, mandates, and policies, while also including measures of success that span these multiple dimensions (Rudd et al., 2018). A systematic review of existing legal frameworks has been suggested as a research need that would help identify opportunities to better implement EBM in the Northeast (Northeast Regional Planning Body, 2017).

Overcoming institutional structures and ensuring stakeholder support were the most commonly described non-science issues limiting EBM implementation in the surveys and interviews (Figure 10). One survey respondent suggested that, “reducing barriers between science, management, and industry” was the most important need for EBM implementation. Because large, accessible databases exist for the Northeast region, and a comprehensive EBM plan has already been cooperatively developed, the Northeast region may be particularly poised to conduct research into the institutional characteristics and incentives needed to improve EBM implementation.

GI 1. Integrated management techniques for fisheries and aquaculture

The need to better understand social and ecological tradeoffs associated with fisheries management and aquaculture development in the Northeast was commonly expressed in surveys, interviews, and regional plans. An interviewed scientist noted that because aquaculture is emerging in the Gulf of Maine, now is the time to “pay attention to how it integrates” into a complex socio-ecological system to make sure the addition of aquaculture is mutually positive. Other survey comments included science needs related to better understanding the social dynamics of fishers as they are affected by changing policies, species distributions, and business models (i.e., shifting from fishing to aquaculture). An interviewed scientist suggested that both formal and informal research into local ecological knowledge would make an important difference in achieving EBFM strategies, noting that traditional experimental design may not be quick enough in such a rapidly changing socio-ecological system. The integration of local knowledge could inform more timely, robust, and place-based policies.

New England’s rich fisheries have played an important historic role in US and European economic and industrial development (NOAA, 2011). The region’s communities have strong ties to their fishing history and still rely on those fisheries for their livelihoods. Many commerical fisheries in the Northeast are reliant on a single species (e.g., lobster in the Gulf of Maine, scallop in Georges Bank), which makes the social-ecological systems in the region vulnerable to fishing losses (Northeast Fisheries Science Center, 2019), and Northeast fisheries have suffered production declines from overfishing. Regional science strategies and planning documents express priorities for coordination and communication to ensure aquaculture and fisheries can be managed for ecological, economic, and cultural sustainability (Northeast Regional Planning Body, 2017; Connecticut Sea Grant, 2018). Improved modeling capabilities that can represent multiple species, regional and local fishing efforts, and economic relationships could support progress in EBM (and EBFM) strategies.

Suggested research to enhance institutional success for EBM in the Northeast included:

- Methods to facilitate socioeconomic adaptation to shifts in natural resource use (such as aquaculture development to supplement declining wild-capture fisheries), including the effectiveness of alternative government incentives (e.g., low-interest loans) that enable a smooth transition to aquaculture

- Identification of the influences of fisheries policy on the fishing industry and local economic sustainability, including effects of fisheries management on fleet condition and processing capacity
- Cascading effects of regional commercial fisheries management (catch limits, heavily used areas) on protected ocean ecosystems (marine protected areas) and the spillover effects of reserves on fisheries to better understand links between different policy objectives and the realized impacts
- Merged and joint analyses of species distribution changes (e.g., induced by climate change) and fishery dynamics (e.g., vessels, fleets) to estimate key inputs to fishery management (e.g., catchability) and uncertainty analyses to reduce risk of management strategies

GI 2. Cost-effective techniques for large-scale and local ecosystem assessment and monitoring

Survey responses and regional priorities identified in reports suggested the need for comprehensive monitoring programs with the capacity to more effectively answer management questions at appropriate temporal and spatial scales. A separately conducted survey of Massacusetts stakeholders highlighted the need for new technologies for efficient and effective monitoring to support better management and policy making (MIT Sea Grant College Program, 2018). Even with the Northeast's extensive datasets, it has been suggested that a lack of time-series data to assess ecosystems in terms relevant to management objectives hinders an integrated understanding of habitat and the societal values provided by coastal systems (Depiper et al., 2017). Regional strategy documents also prioritized management, monitoring, and planning tools and approaches that could improve ecosystem protection and restoration efforts (e.g., Maine Sea Grant 2017).

The following examples from sources in the Northeast could enhance EBM strategies with ways to use and improve the extensive data collections that already exist for the region:

- Strategies to integrate data management, synthesis, and application among agencies for timely identification of the impacts of management actions and to guide adaptive management

- Development of programs and methods to support targeted monitoring to detect change and indicator development for connecting observations to ecosystem-level change (e.g., resilience indicators)
- Monetary and effort resources to support ways to use the extensive data collections that already exist in the Northeast to improve ecological understanding (e.g., mining big data)
- Innovative methods (e.g., institutional structures, computer tools, remote sensing, citizen science) to improve the use of monitoring and scientific findings in management

GI 3. Enhanced communication and consensus building

The need to further engage community groups, government agencies, and other organizations in decision making was consistently mentioned in our survey, follow-up interviews, and in regional planning documents (e.g., Maine Sea Grant 2017, NOAA Fisheries 2019). A repeated sentiment in survey responses placed an increasing responsibility on scientists to improve communication, accessibility, and relevance of their work. Survey responses naming critical science for EBM included the need for "better understanding of the science needs of decision makers," ways to "connect science to management," and "more effective science translation." An interviewed scientist and policy maker suggested that scientists could better support EBM with additional training in communications to more thoughtfully connect with managers.

"They have to believe in it."

-Responding Policy Maker/Resource Manager

One interviewed respondent pointed out that the most successful strategy for encouraging EBM was reminding people that it does not require tossing out an old system and building a new one. They described EBM as a way of weaving together management structures. Two other interviewed respondents said that buy-in from users and local involvement in management were the key ingredients for achieving EBM. In a separate survey question, existing institutional structures and stakeholder buy-in were the most commonly described barriers to EBM (Figure 10). The experiences of interviewees suggested that when these two barriers are overcome, EBM can make important strides toward acceptance and implementation. Methods to co-develop research based on stakeholders' values and managers' science needs may support institutional shifts toward greater EBM adoption.

The following are examples of strategies that Northeast respondents and sources suggested may improve the capacity for EBM:

- Methods to improve interagency and stakeholder communication (e.g., designing communication strategies to promote behaviors that reduce risk to ecosystems)
- Advancing and applying social science on methods to identify shared priorities and move people from entrenched positions to consensus (e.g., collaborative modeling, facilitated stakeholder workshops)
- Evaluation of potential incentives to promote public, institutional, and political support for EBM planning and implementation
- Strategies to encourage better alignment of research (objectives and timing) with needs of local/regional decision makers (e.g. cooperative research design)

CONCLUSION

The Northeast has extensive datasets, cooperative partnerships, and a regional dedication to ecosystem-based strategies. However, our survey and interview participants suggested important biophysical and social science needs to fulfill their expectations for successful EBM. The science gaps and research examples described herein are a snapshot of regional priorities for coastal EBM. Many of the key findings of the 2008 Prospectus (NOAA National Centers for Coastal Ocean Science, 2008) and the Gulf of Maine EBM assessment (Taylor, 2008) were similarly reflected in our study, suggesting some persistent science needs for EBM in the Northeast. For example, the 2007 surveys and workshops conducted for EBM in the Gulf of Maine concluded the needs for tools to evaluate cumulative impacts of human activities, prioritize conservation and management actions, understand effects of management actions, and identify tradeoffs among uses and ecosystem function (Taylor, 2008). The 2008 Prospectus similarly described needs for coupled physical and biological models to understand and predict ecosystem change and minimize negative impacts of human uses and development (NOAA National Centers for Coastal Ocean Science, 2008). These same tools were prevalent needs appearing throughout our analysis. However, our results also recognized a broadening of the objectives of the science needs in the region. This analysis suggested an increased focus on needs for socio-ecological science that would support management in addressing those long-standing ecosystem concerns, such as methods to enhance communication and consensus building among stakeholders and improve the connection between science and management.

Critical and Emerging Science to Support Ecosystem-Based Management

Mid-Atlantic

Ecosystem Science

- Biogeochemical and ecological connectivity between watersheds and estuaries
- Changes in habitats and productivity with climate change
- New approaches to advance ecosystem modeling and habitat mapping
- Emerging contaminants

Socio-Ecological Science

- Effects of ecosystem management actions on human well-being
- New methods to enhance communication and consensus building for ecosystem sustainability
- Multi-use conflict analyses for in-water activities
- Innovative solutions and technologies to reduce environmental impacts of coastal development

Governance and Incentives

- Cost-benefit analyses of potential methods for adaptation to climate change
- EBM effectiveness and implementation progress
- Strategies for integrating science and management objectives

MID-ATLANTIC

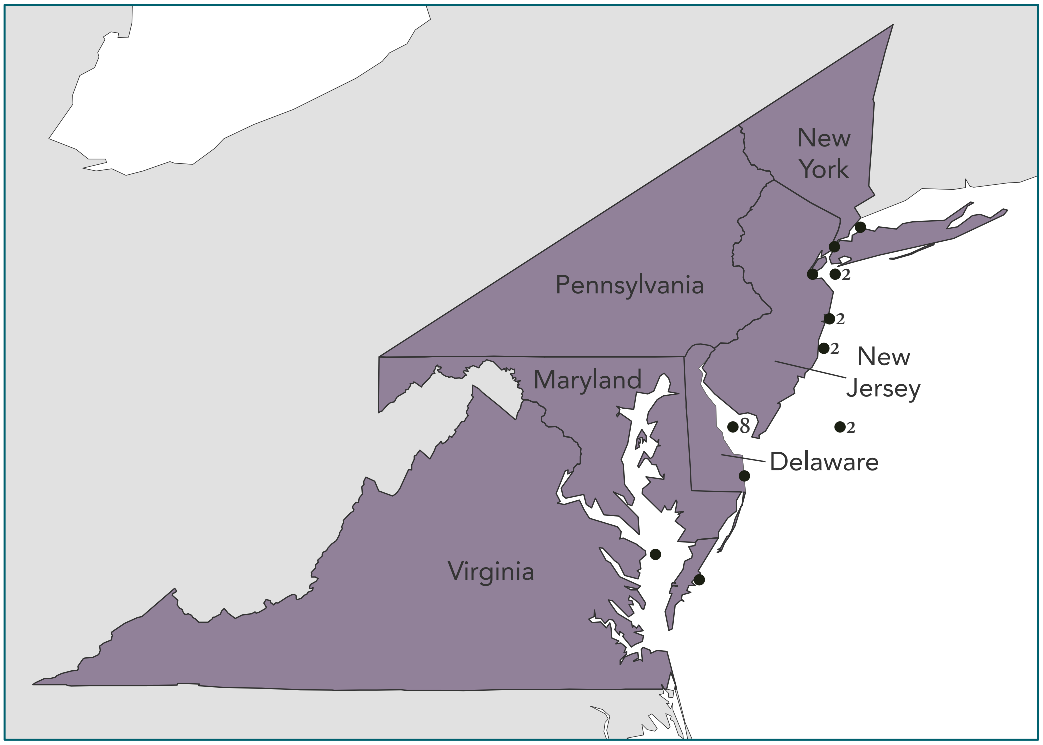


Figure 12. Mid-Atlantic region and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The coastal US Mid-Atlantic region described herein features over 10,500 miles of coastline of Virginia, Maryland, Delaware, New Jersey, and New York. Several large estuaries (Chesapeake and Delaware Bays and Long Island Sound) are prominent features and shallow coastal lagoons and wetlands are common throughout the region. The Mid-Atlantic coastal waterways and estuaries receive inputs from a much larger watershed (>100,000 square miles) that also includes land in the District of Columbia, Connecticut, Pennsylvania, Vermont, and West Virginia.

Features of EBM in the Mid-Atlantic

Ecosystem-based strategies have gained a foothold in Mid-Atlantic coastal resource management. Chesapeake Bay scientists and managers led the region, publishing one of the nation's first fishery ecosystem plans (Chesapeake Bay Fisheries Ecosystem Plan Advisory Panel, 2006). In 2009, the governors of New York, New Jersey, Delaware, Maryland, and Virginia signed an agreement to launch a coordinated effort toward EBM for ocean conservation (Mid-Atlantic Governors, 2009). Regional ocean plans and guidance documents express a commitment to an EBM approach (e.g., Mid-Atlantic Regional Ocean Planning Body 2016, Maryland Sea Grant 2017, New Jersey Sea Grant Consortium 2018). The Mid-Atlantic Fishery Management Council generated a strategy for an ecosystem approach to managing fisheries in consideration of interactions among species, climate, habitat, and human use (Gaichas et al., 2016). NOAA's Northeast Fisheries Science Center has been producing annual State of the Ecosystem reports with the Mid-Atlantic Fishery Management Council since 2017 to support EBM and EBFM strategies.

Perceptions of EBM in the Mid-Atlantic

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Mid-Atlantic region, we received 37 survey responses and conducted follow-up interviews with three of these survey participants (Appendix A: Figure A3). Survey respondents self-identified their roles (Table 2A) and we identified organizational affiliations from the email addresses provided in survey responses (Table 2B). Thirty-five respondents agreed that EBM was a goal in their work and that they provide guidance for management decisions. Thirty respondents said that EBM was currently being used in their work.

Table 2. Self-identified work titles (A) for Mid-Atlantic respondents and level of organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	17
Scientist & Resource manager	5
Scientist, Resource manager, & Policy maker	1
Resource manager only	4
Policy maker only	2
Resource Manager & Policy maker	2
Did not identify as above	6
Total	**37**

B.

Organization	
Federal government	8
State government	8
Non-governmental organization	4
University	8
Unidentified	9
Total	**37**

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. One respondent described two separate locations, thus the results and discussion that follow describe perspectives of EBM for 38 locations.

The general priorities and views of respondents in the Mid-Atlantic region were similar to those in other regions. The majority of respondents indicated that there were important science and communication needs that, if met, would enhance the likelihood of successful EBM implementation in the region (Figure 13). Among the US mainland regions in our survey, a greater proportion of respondents in the Mid-Atlantic indicated views of some success in their experience with EBM. Respondents *somewhat* agreed that EBM was successfully being implemented in 16 of the 38 locations described (Figure 13). No respondent strongly agreed.

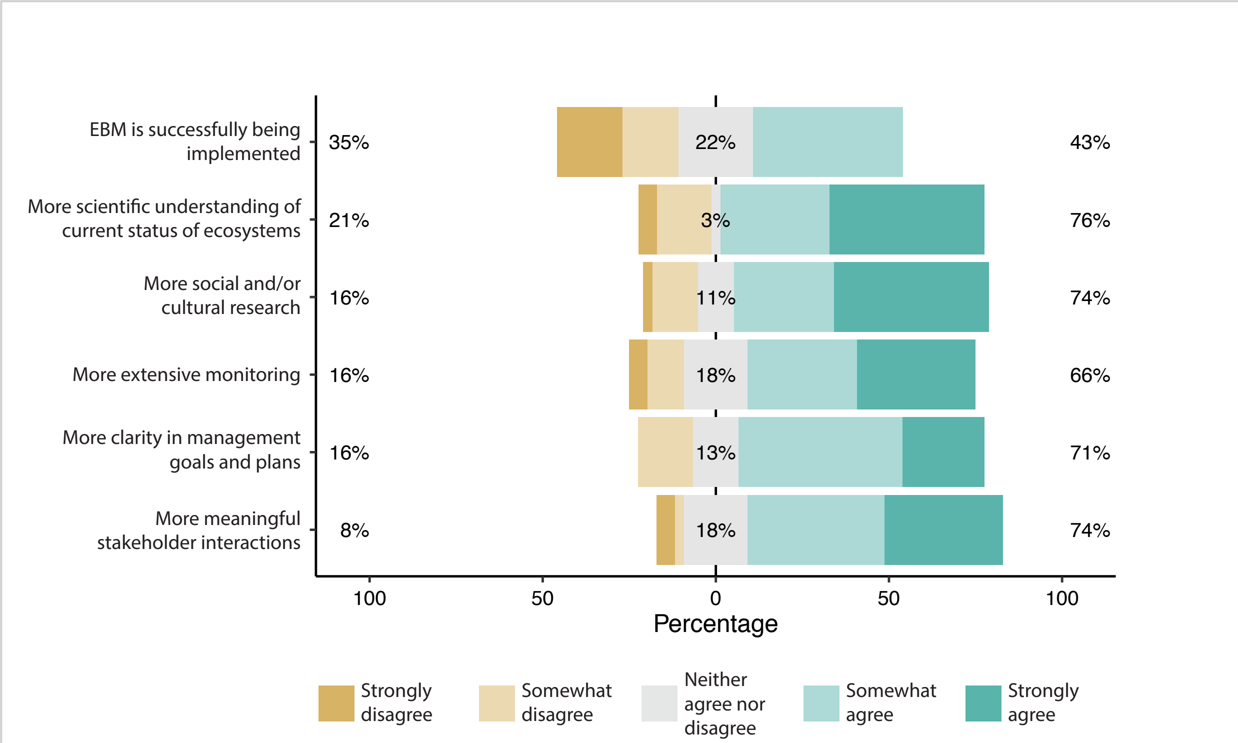


Figure 13. Practitioner opinions on needs before fully implementing EBM in locations in the Mid-Atlantic (SQ12, n=38). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad environmental and socioeconomic issues in locations in the Mid-Atlantic region, *water quality*, *habitat integrity*, and *coastal resilience* were most commonly rated as very or extremely important issues (Figure 14). Greater than 90% of online survey respondents for the Mid-Atlantic designated *habitat integrity* and *coastal resilience* as extremely or very important for the locations they described (Figure 14). In the 21 write-in responses listing additional issues that were very or extremely important for a location, the most common replies fell into the following themes: climate change (9), fisheries (8), and sea level rise (7). We expected to see the subject of fisheries in these responses as EBFM is an existing effort in the region. We did not explicitly list fisheries in the survey to encourage other less prevalent issues. We also intentionally omitted climate change from the list under the rationale that its effects would be captured within the listed issues. Results of our analysis for several regions, including the Mid-Atlantic, suggested that these topics were regarded by many respondents as distinct environmental concerns within EBM.

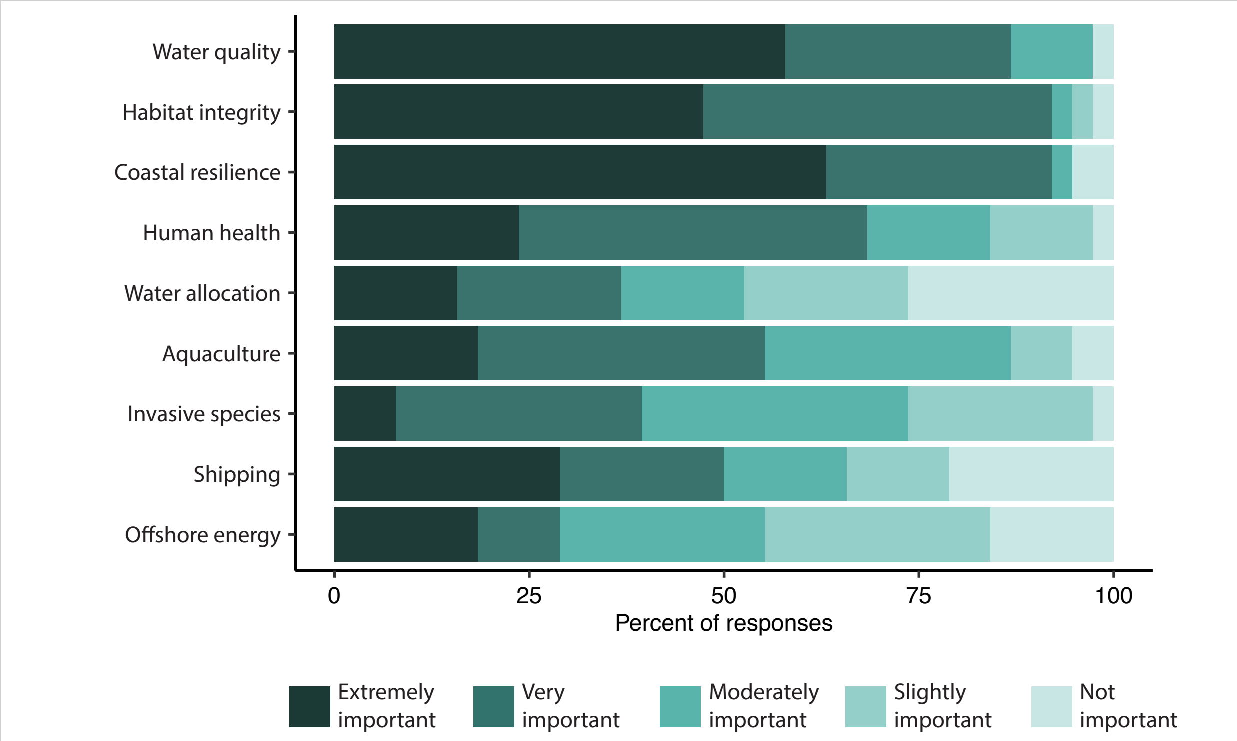


Figure 14. Priority issues as described by online survey respondents (SQ7, n=38).

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). Thirteen of the 32 Mid-Atlantic respondents that ranked the listed elements of EBM derived from our operational definition selected *implementing an interdisciplinary approach* as the most difficult aspect of EBM to achieve (Figure 15). There was some suggestion that the crosscutting science required to achieve EBM needs to be more explicitly stated and worked into management planning, including funding for personnel.

Understanding interconnected processes and *developing actionable goals* were other aspects commonly ranked as either the most or second-most difficult to achieve (Figure 15). Results in the Mid-Atlantic region suggested that, overall, practitioners have a good understanding of desired ecosystem states (interpreting healthy, productive, and resilient ecosystems was considered relatively simpler than other aspects of EBM), but that developing and achieving goals through coordinated effort has been the primary challenge. In follow-up interviews we heard that some of the difficulties for EBM were related to a lack of methods to quantify how management actions affect socioeconomic and biogeochemical processes in complex coastal environments (i.e., cause and effect) and limitations on taking action (e.g., scientific uncertainty or conflicting interests).

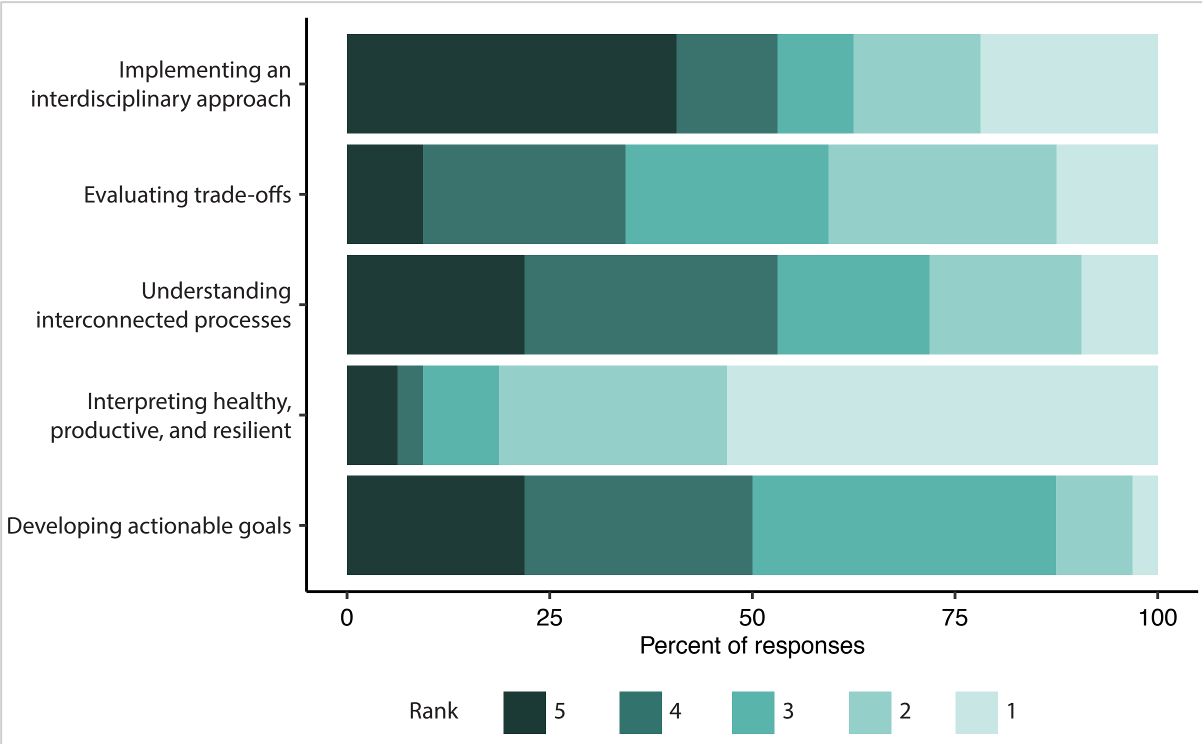


Figure 15. Perceived relative difficulty of EBM attributes, where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=32).

Although the majority of survey respondents agreed that more science is needed before fully achieving EBM (Figure 13), *monitoring*, *data availability*, and *understanding of ecological linkages* were considered by greater than 50% of respondents as currently supporting EBM planning and implementation (Figure 16). Management characteristics, such as competing mandates and authorities and political and stakeholder support were frequently considered to be hindering EBM implementation. Some respondents commented that existing institutional design prevents coordination among agencies, which can impede regional EBM.

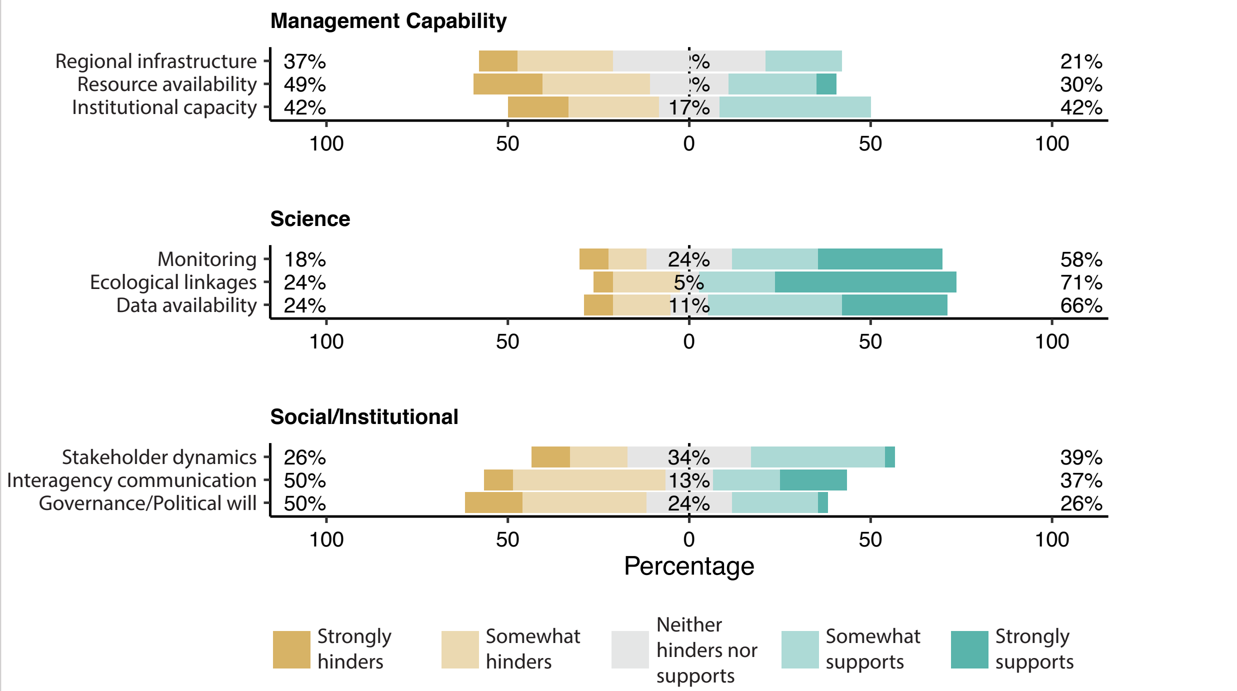


Figure 16. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11, n=38).

Responses to the question, *What is the biggest non-science barrier to EBM?* commonly referred to a lack of communication among agencies and a lack of support from stakeholders and political leaders (Figure 17). Respondents noted that many agencies do not have personnel strictly dedicated to cross-boundary work or interagency communication campaigns, but our interviews suggested that communication of data and emerging science among the scientific and resource management community is critical to inclusivity and stakeholder buy-in, and ultimately for implementing EBM in the region. Respondents also suggested that the limited examples of EBM in practice contributes to the difficulty in gaining political and public support for changing management strategies.

Figure 17. Coded themes of responses describing non-science barriers to EBM (SQ42, n=31) in the Mid-Atlantic region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. Fisheries issues were mentioned in 12 of the 36 responses and represented the most common general theme in the Mid-Atlantic region (Figure 18). Other frequently suggested science topics were related to understanding socioeconomic (10 responses) and ecological (9 responses) effects of management actions (Figure 18).

> "In many areas there are critical pieces of science that are not available on a regular basis for management to be effective."
>
> – Responding Scientist

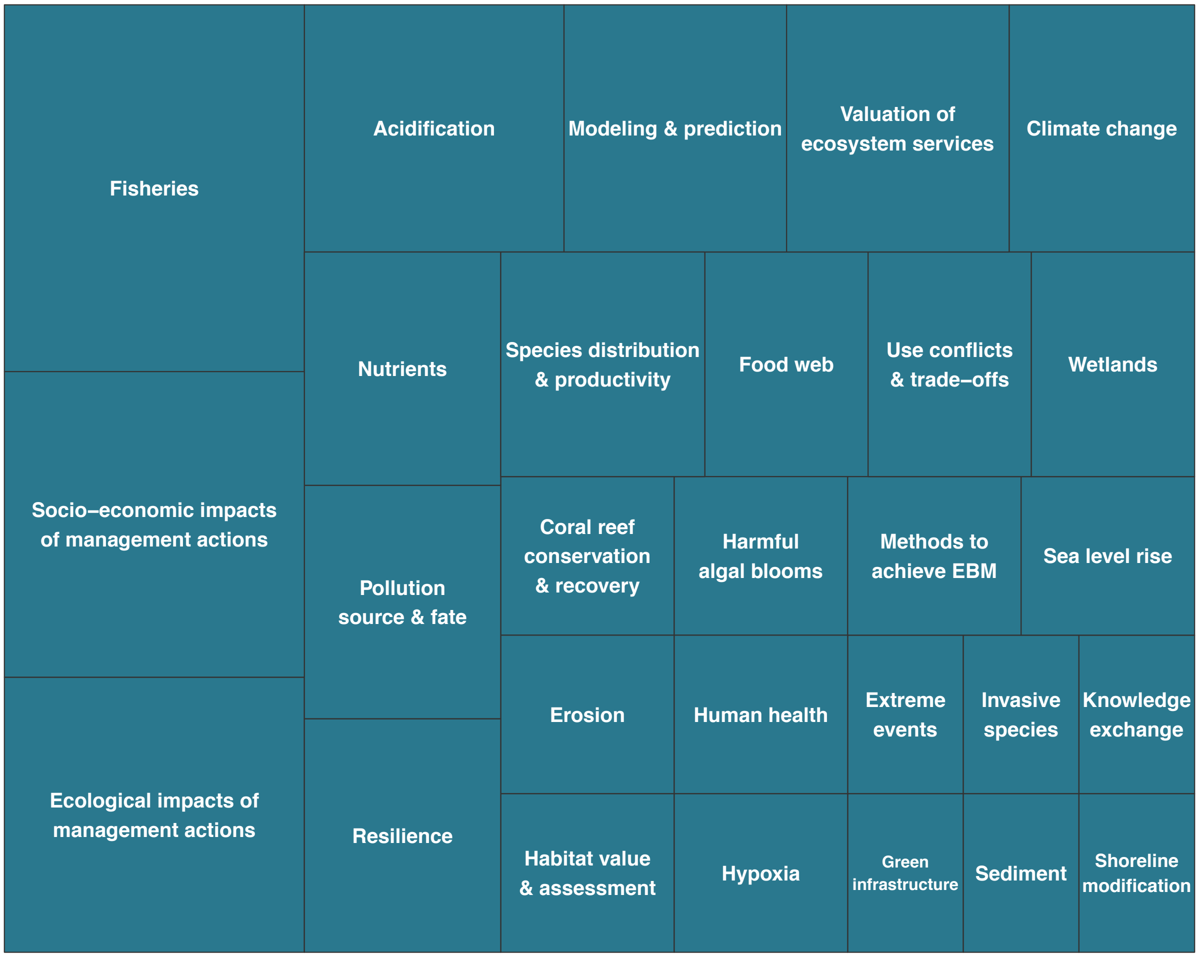


Figure 18. Topics appearing more than once in survey responses describing critical science needs for EBM in the Mid-Atlantic (SQ10, n=36). Larger boxes correspond to more frequent mentions.

Survey results and comments in the Mid-Atlantic region had many similarities with the priorities described in the regional literature. For example, respondents and regional planning documents prioritized approaches to manage for sustainable ocean uses, with a common focus on variability and interconnectivity in species and habitats. However, survey and interview responses also emphasized the need for monitoring the effectiveness of management and evaluating and communicating tradeoffs.

Critical and Emerging Science to Support EBM in the Mid-Atlantic Region

One of the purposes of this project was to provide an update to the Regional Ecosystem Research Prospectus (2008 Prospectus), a document that has helped guide regional coastal science research to address EBM and other management needs (NOAA National Centers for Coastal Ocean Science 2008). Broad research priorities for the Mid-Atlantic region presented in the 2008 Prospectus included improving understanding and predictive capabilities of the impacts and linkages among climate and human alteration of water quality and coastal habitats. The guide further described a need for the development of population and ecosystem models to improve the ability to manage, restore, and sustain healthy fish and wildlife populations. This effort updates and expands upon those recommendations.

Ecosystem Science

Survey responses and regional reports both describe a need for new ecosystem-level research to integrate cross-cutting natural science issues in the Mid-Atlantic. In particular, the 2008 Prospectus recognized a need to focus research in the region toward an increased understanding of ecological linkages (NOAA National Centers for Coastal Ocean Science, 2008). This need was more recently emphasized within the Mid-Atlantic Fishery Management Council's Ecosystem Approach to Fisheries Management Guidance Document (Mid-Atlantic Fishery Management Council, 2019). Of specific note, better characterization of cause and effect relationships in Mid-Atlantic coastal systems would advance the ability to target management activity and gap-filling research. For example, water pollution sources, including nutrients and toxic contaminants, are not well constrained everywhere, which hinders cost-effective targeting of cleanup resources.

ES 4. Biogeochemical and ecological connectivity between watersheds and estuaries

Pollution source and fate was described by 15% of survey participants responding to the question of critical science to support EBM. Reducing pollutants (particularly nutrients) entering from the watershed was prioritized in all 13 management plans or strategy documents we reviewed for the Mid-Atlantic region. There are still important science needs regarding the effects of nutrients and other pollutants from watershed runoff on nearshore environments (see e.g., Fennel and Testa 2019). Extensive research has described pollution sources and ecological effects. However, details such as nutrient speciation and legacy effects are still insufficient for precise characterization and prediction of their effects in estuaries.

Within this category, the following research needs were provided in surveys and interviews:

- Detailed research on nutrient speciation and legacy effects to more precisely identify opportunities for improving estuarine habitat
- Characterization of exchanges of materials and organisms and influences on estuarine habitats
- Nutrient biogeochemistry to support more accurate and timely harmful algal bloom and hypoxia prediction/warnings
- Advancement of DNA fingerprinting techniques to improve understanding of pollution sources

ES 5. Changes in habitats and productivity with climate change

Research is needed to better describe how habitats are likely to shift with the various effects of climate change and the consequences for species distribution, productivity, and behavior. A common request in online surveys was for tools and assessments that could support forecasting changes in species distribution and productivity under climate change.

Climate change is expected to alter ecological processes in the Mid-Atlantic region and human behavior is creating uncertainty as to the combined effects on coastal areas, aquatic food webs, and fisheries. Changing water temperatures, acidification, and ocean circulation patterns are influencing the base of the food web, thus affecting productivity (Olsen et al., 2018; NOAA Fisheries, 2019g) and leading to uncertainty in future species distribution and abundance (Gaichas et al., 2018; Free et al., 2019; IPCC, 2019). Some of the fastest-warming waters are on the US Atlantic continental shelf (NOAA Fisheries, 2019g). In such an open system, these rates of warming have led to distributional shifts in many species (Nye et al., 2009; Gaichas et al., 2018).

The following are examples of science needs that appeared through our analysis:

- Ecosystem factors influencing species distribution, including intra- and inter-annual variability
- Changes in species interactions (terrestrial and aquatic) with habitat migration
- Effects of changing climate conditions on species distribution, growth, and reproduction
- Effects of climate change and habitat migration on energy transfer throughout aquatic food webs
- New technologies that could be deployed in the environment to assess habitat status and change
- Exploration of how the biogeochemical-ecological nexus will change under climate change to support predictive models

ES 6. New approaches to advance ecosystem modeling and habitat mapping

The 2008 Prospectus identified a need for better ecosystem models to describe multi-species interactions and predict multiple impacts (NOAA National Centers for Coastal Ocean Science, 2008). Identifying species with strong interactions or key foraging species may help prioritization for EBM (Gaichas et al., 2016; Buchheister et al., 2017). Habitat mapping and ecosystem characterization are important for developing decision tools for coastal resource managers. The Mid-Atlantic Regional Ocean Plan prioritized a need to map shifts in ocean species and habitats (Mid-Atlantic Regional Ocean Planning Body, 2016).

Practitioners in the Mid-Atlantic suggested they would particularly benefit from models that have “forward-looking power” and provide confidence and accountability in decisions based on them. Because there is always scientific uncertainty, managers and policy makers need models that can support consensus decision making that is robust to that uncertainty and have processes in place to allow for timely adaptation. This process is currently playing out with respect to the adoption of Ecological Reference Points (ERPs) for Atlantic menhaden to inform management (SEDAR, 2020) through the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC process involved comparisons of forecasts and performance of multiple models under the same conditions. These comparisons have led to the development of a full ecosystem model (e.g., Buchheister et al. 2017) and a reduced model of intermediate complexity (MICE) as compatible partners to provide both tactical (i.e., ERPs) and strategic advice. Analysis of existing long-term datasets to determine baseline variation would be beneficial for isolating ecosystem response to environmental change and management actions.

Seagrass as “the nexus of natural and human” environments in Barnegat Bay, NJ

Understanding submerged aquatic vegetation was one of three main priorities for the Mid-Atlantic in the 2008 Prospectus. One scientist from our study suggested that anthropogenic nutrients are not the whole story of seagrass decline in Barnegat Bay. While nutrient concentration monitoring is ubiquitous, and seagrass coverage is broadly surveyed in the Mid-Atlantic, the respondent suggested that perhaps more of the story of water quality could be told by more holistic regional science. In Mid-Atlantic bays and estuaries, where watershed inputs are intrinsically linked with greater coastal and shelf dynamics (e.g., ocean acidification, water temperature) and human use (e.g., boat traffic, non-native species introduction, aquaculture) more strictly defining “nexus” indicators could be broadly advantageous for management.

The following research could support predictive modeling with greater confidence for decision-making:

- Data synthesis across multiple databases and sources (including emerging measurements such as ocean observing) to enable development of statistical relationships and new physical and ecological models, and enable coupling of models
- Methods to support coupled food web and water quality (elemental cycling) models
- Development of predictive models of ecosystem change with climate change at management-relevant scales (e.g., species distribution, changing salinity gradients)

ES 7. Emerging contaminants

Although emerging contaminant research was not identified as a top priority in our survey, it has been prioritized in regional planning (e.g., Hudson River Estuary Program 2010, Maryland Coastal Bays Program 2015). The Chesapeake Bay Program's Scientific and Technical Advisory Committee recently held a multiday workshop to highlight research gaps in understanding the effects of toxic contaminants and potential management approaches since this is an area that has taken a back seat to nutrient and sediment reductions (Chesapeake Bay Program, 2019). The densely populated Mid-Atlantic region may have a relatively high risk of human-derived pollutants influencing coastal systems. As a result, identifying emerging contaminants and approaches to mitigating their effects on coastal marine systems and human uses of those systems is a priority.

Increasing concentrations of personal care products and pharmaceuticals in the wastewater stream is an area of emerging concern (Tijani et al., 2016; He et al., 2019). For example, increases in concentrations of chemicals that disrupt endocrine pathways in Mid-Atlantic rivers and bays have been shown to feminize fish (Blazer et al., 2007; Bugel et al., 2010). The broader impacts of these products on the marine environment are not fully understood.

Plastic pollution is a contaminant of concern in bays, estuaries, and the coastal ocean in the Mid-Atlantic. Research has indicated plastics and microplastics are pervasive across marine taxa (Santillo et al., 2017). The Mid-Atlantic is an important producer of bivalves such as oysters, clams, and scallop, and research has shown these taxa are particularly affected by ingestion of microplastics. The impacts of the plastics on the health of the organisms and human health are poorly described.

Research suggestions for emerging contaminants in the Mid-Atlantic region included:

- Impacts of plastic pollution in marine environments, particularly microplastics in oysters, clams, and scallop and human health implications
- Effects of chlorides/deicers used in the watershed on water quality and subsequent impacts on nearshore environments
- Effects of pharmaceuticals, agrochemicals, and endocrine disruptors on marine life cycle and reproduction
- Ecosystem effects of per and Polyfluoroalkyl substances (PFAS and PFOS) associated with either production or application on military and civilian airfields

Socio-Ecological Science

One source in the Mid-Atlantic summed up the perspective of many respondents by saying that considering natural and human systems as separate is not realistic. Working within a social-ecological framework may be the most important scientific link for EBM. All three interviewed participants expressed the need for better social-ecological understanding.

Cultural resources and sense of place are important aspects of the Mid-Atlantic coast. The region was historically home to Native American peoples and is currently home to 27 state or federally recognized tribes still participating in traditional practices (Mid-Atlantic Regional Ocean Assessment, 2019). Coastal counties in the Mid-Atlantic region are home to nearly 34 million residents and the population is steadily increasing (US Census Bureau, 2010; NOEP, 2018). Regional watermen[5] are a subject of cultural pride and an example of social resilience (Boesch and Goldman, 2009). Regional cultural identities have been shaped over generations by deep ecological knowledge and experience of fishing families and coastal residents. The following science suggestions could help promote the efficiency of social-ecological systems thinking in management and generate net increases in well-being.

[5] Watermen are people who work or live on the water, e.g., fishers, boats for hire, etc.

SES 3. Effects of ecosystem management actions on human well-being

Social and economic impacts of management actions were among the most frequently suggested research needs to enhance EBM, mentioned in 10 of 36 responses in Mid-Atlantic locations (Figure 18). This concern was echoed in the Mid-Atlantic Fishery Management Council's plan to address a "lack of adequate policy analysis of the social and economic consequences of management actions" (Mid-Atlantic Fishery Management Council, 2015). New knowledge of the links between ecosystem services and the costs and benefits of management actions are needed to advance EBM in the Mid-Atlantic.

Specific research directions identified were:

- New methods for identifying and quantifying social benefits of restoration/conservation in coastal systems
- Valuation of ecosystem services (described by 18% of Mid-Atlantic survey respondents)
- Evaluation of research gaps for assessing tradeoffs of alternative management scenarios
- Management strategy evaluations at the ecosystem level to explore the consequences of management actions/projects (direct and indirect effects) on select ecosystem services (e.g., fisheries, tourism, community sense of place)
- Characterization of vulnerable human communities to support equality in management/resilience strategies

SES 4. New methods to enhance communication and consensus building for ecosystem sustainability

The most commonly described barriers to EBM in Mid-Atlantic survey responses were related to communication and stakeholder buy-in (Figure 17). When asked about the most effective strategy for encouraging EBM, one interviewee described the inclusivity and sense of community experienced in a well-managed, interdisciplinary, and stakeholder-engaged project. Methods to develop new and existing social science (e.g., environmental psychology, ethnoecology) to help understand behavior and enhance stakeholder processes will help to expand EBM in the Mid-Atlantic.

New social-ecological research in the Mid-Atlantic would serve to improve understanding of the benefits of conserving or restoring ecosystems and their distribution across socio-demographic groups. A suggested approach was the development of integrated models that are able to capture local knowledge and values as well as quantitative relationships of major ecosystem metrics that could help coordinate research with managers' needs and tailor models to managers' questions. Economic valuation may be part of this approach but socioeconomic decision support tools can also be well supported by understanding the direction and magnitude of causal connections between management decisions and socially meaningful system endpoints (Wainger and Boyd, 2009). Such tools can be used to cost-effectively target management effort and address equity among user groups.

The following are potential research directions to enhance communication and consensus building to achieve shared goals for ecosystem sustainability:

- Distribution of benefits of conserved or restored ecosystems across socio-demographic groups
- Research opportunities provided by social media or other novel data sources to gain new knowledge of social networks, environmental perceptions, and behaviors
- Evaluation of the multiple and intertwined benefits from restored ecosystems to compare benefits to costs
- Characterization of vulnerable communities to support equality in management/resilience strategies

SES 5. Multi-use conflict analyses for in-water activities

Multi-use conflict analyses are needed to inform many kinds of local and regional ocean use planning. Respondents had questions about how offshore wind farms, potential oil exploration, and aquaculture will integrate into an already busy shipping and fisheries region. Further, there are concerns that the continuity of long-term data sets and scientific research may be at risk.

Aquaculture in the Mid-Atlantic region is a growing industry that could conflict with or complement other ocean uses. One interview respondent discussed the desire for a multi-use management plan for Barnegat Bay, NJ that ensured adequate shellfish habitat and aquaculture areas. Another interviewee discussed the water quality and structural benefits provided by shellfish aquaculture in Delaware Bay but cited difficulties in permitting for such activities. NOAA Sea Grant is urging and supporting new technologies for sustainable aquaculture in the region (e.g., New Jersey Sea Grant Consortium 2018, NOAA Sea Grant 2019) to enable deployment in multi-use areas.

A specific issue identified for the Mid-Atlantic was research to evaluate the effects of offshore wind energy and the potential for user conflicts. Although offshore energy projects will be important for meeting future energy supply challenges in the region and the nation, effects on the marine environment and commerce are still unknown (Mid-Atlantic Regional Ocean Assessment, 2019). While there are currently no offshore wind farms in operation in the region, there are commercial leases granted for it in all five Mid-Atlantic states (BOEM). Respondents suggested research that could describe how offshore energy infrastructure will influence habitat, species distribution, and migration.

The research suggested by survey and interview participants included:

- Quantification and potential for mitigation of tradeoffs of wind energy infrastructure
- Cascading effects of multiple ocean uses on habitats
- Innovative solutions for alternative ocean uses
- Identification of water quality and ecosystem tradeoffs related to aquaculture
- Use of spatial planning tools to evaluate offshore wind infrastructure

SES 6. Innovative solutions and technologies to reduce environmental impacts of coastal development

With 34 million people living in Mid-Atlantic coastal counties (US Census Bureau, 2010), methods to lessen anthropogenic impacts and retrofit/adapt human communities will need to part of sustaining future ecosystems. Solutions and technologies are needed in a wide variety of situations including data collection (e.g., promoting verifiable citizen science), pollution control, waste reduction, wildlife-compatible infrastructure, and environmental restoration. For example, research is needed to provide shoreline stabilization in ways that do not eliminate shoreline habitat (Hudson River Estuary Program, 2010) and to determine the effectiveness of current living shoreline approaches for supporting species (US Geological Survey, 2015).

The following research could allow for innovation and sustainability in social-ecological systems and efforts to maintain ecosystem integrity and function:

- Effectiveness of green infrastructure at reducing pollution runoff and serving species' habitat needs
- Influences of shoreline modification on nearshore aquatic systems on terrestrial, beach, wetland, and transitional habitats
- Effectiveness of current policies of shoreline erosion control for delivering the highest overall benefits to social-ecological systems
- Identification of effective programs for promoting alternative building types and land use planning

Governance and Incentives

Institutional innovation has been identified as a means to enhance knowledge exchange among coastal marine scientists and policy makers (Cvitanovic et al., 2015). Many Mid-Atlantic respondents felt such innovation was needed to achieve more effective coastal management. Greater than half of Mid-Atlantic survey participants responded that interagency communication hinders EBM planning and implementation (Figure 16) and that jurisdictional boundaries and existing governance structures were substantial barriers (e.g., Figure 17). In the Chesapeake Bay, comprehensive management planning is well supported in public and policy spheres, but decision makers still struggle to work at the ecosystem scale due to lack of authority and resources (Boesch and Goldman, 2009), weak integration among agencies, and perceptions of relative costs to benefits (Rudd et al., 2018).

> "We need an approach that facilitates [EBM] thinking as opposed to silos working on individual portions."
>
> – Responding Resource Manager

GI 4. Cost-benefit analyses of potential methods for adaptation to climate change

An overriding concern in Mid-Atlantic survey responses was adapting to climate change, specifically to sea level rise. Scientists and resource managers throughout the Mid-Atlantic region expressed the importance of managing for coastal resilience in a changing environment. Greater than 90% of online survey respondents describing locations in the Mid-Atlantic recorded coastal resilience as extremely or very important (Figure 14), which is not surprising given the rapid rate of change. The Mid-Atlantic bight has experienced sea level rise at rates three to four times greater than the global average (Sallenger et al., 2012), increasing erosion and flooding (Titus et al., 2009). Sea level rise is also expected to have dramatic effects on coastal wetlands and submerged aquatic vegetation in the Mid-Atlantic region, potentially increasing the vulnerability of important commercial and protected species (Jones et al., 2009).

Public consciousness of coastal vulnerability has grown in the Mid-Atlantic region since superstorm Sandy in 2012. The increasing impacts of coastal storms were the most frequently mentioned concern for wetland and shoreline preservation by external stakeholders in a survey conducted by the New Jersey Department of Environmental Protection (2015). After the storm, there appeared substantial willingness to accept new regulations for coastal resilience to climate change effects but little support to raise revenue to implement policies (New Jersey Climate Adaptation Alliance, 2013). However, the storm spurred the appropriation of over $800 million for the Department of the Interior to research and address coastal vulnerability to storms and sea level rise in the affected area (US Congress, 2013).

The Mid-Atlantic region would benefit from analyses of potential socioeconomic implications of climate change under different scenarios, including both infrastructure stabilization and human retreat. Practitioners expressed a desire for projections of likely future states of Mid-Atlantic coastal systems and a better understanding of specific sources of vulnerability. For example, cost-benefit analyses could help to better understand types of vulnerabilities that are most cost-effective to manage as well as recognize what costs are avoided by restoration and resilience investments.

The following research needs, if fulfilled, could improve understanding of costs and benefits for climate change adaptation:

- Evaluation of the sufficiency of current management strategies to meet future needs (e.g., will stormwater policies run out of land for placing BMPs?)

- Sources of heterogeneity that should be considered when designing adaptation strategies (geologic, biogeochemical, human use, socio-demographics)
- Identification of types of institutions or programs that could ease social transitions associated with retreat
- Identification and potential for quantification of direct and indirect social benefits of improved resilience
- Development of tools for determining how different adaptation strategies will affect well-being and accommodate ecosystem change
- Assessment of coastal wetland environments to mitigate climate change effects and coastal hazards

GI 5. EBM effectiveness and implementation progress

Nearly 40% of critical science responses indicated scientists and managers are seeking to understand the impacts of management actions in the Mid-Atlantic. The region has a long history of active ecosystem management projects that offers an opportunity to explore methods and metrics for measuring progress in the ecosystem-based approach.

The following are examples of research on institutional efforts and outcomes that could guide consensus-building techniques across jurisdictions and institutions toward achieving EBM goals:

- Identification of effective incentives for making individual or institutional change
- Knowledge exchange of EBM experience to increase the effectiveness of future actions
- Development of tools (metrics, monitoring, and modeling) for assessing ecosystem responses to EBM actions
- Processes to make monitoring or research results more accessible to decision makers for adaptive management
- Local-scale characterization of the cumulative effects of management actions
- Management strategy evaluations at the ecosystem scale that allow the interaction of management and ecosystem response to be evaluated

GI 6. Strategies for integrating science and management objectives

Coastal resource managers in the Mid-Atlantic expressed a need for science that can be more directly applied to problem-solving. In particular, survey respondents were concerned that existing models lacked the detail that made model results relevant to specific decisions. Experience in the Mid-Atlantic suggests that the involvement of managers at the scientific research proposal phase could be one way to generate science more applicable to management and tradeoff analysis (Turner and Jordan, 2017). Additional research could support greater understanding of the conditions that make collaboration among managers and scientists possible and successful.

In addition to more applicable models, respondents expressed a desire for improving the effectiveness of adaptive management strategies. Research was suggested to address questions of what makes systems successful at collecting appropriate data, funding timely data analysis, and applying findings to refine actions. Complementary research needs were related to the legal/social drivers that lead to program formation or success.

Respondents also had more basic questions about effective strategies for understanding and using information about tradeoffs and promoting social efficiency of management (generating net increases in well-being). They were interested in efforts to effectively engage stakeholders in shared governance of resources (e.g., Ostrom 1990).

Suggestions for integrated research included:

- Evaluation of the characteristics of adaptive management that promote success
- Review of case studies where managers or other stakeholders informed modeling or co-developed models with scientists to ensure applicability of results to decisions
- Identification of types of benefit measures (monetary values, benefit-relevant indicators, ecosystem service quantities) that would be most useful for decision makers
- Methods to support consensus-building for management recommendations
- Development of effective methods for tradeoff analysis, including identifying gaps in social and ecological effects of management actions

Conclusion

Our analysis suggested that progress toward EBM in the Mid-Atlantic is supported by the strong existing science and management agencies that have encouraged efforts toward EBM. Survey and interview participants suggested that there are important needs for understanding the socioeconomic and ecosystem effects (both positive and negative) of management actions that, if better understood and communicated, would enhance EBM implementation strategies. According to the survey and interview participants, uncertainty and misconceptions about what EBM entails can create conflict. However, informants expressed confidence that an ecosystem approach can be well supported at local levels and described increasing willingness for EBM within their organizations. Sources in the region commonly called for new science to improve the understanding of interconnected systems and anticipated effects of climate change on species and human well-being. Several people noted a lack of funding and institutional capacity to allow for cross-boundary opportunities. Overall, the individuals we encountered through our process were enthusiastic about the potential for EBM to help solve some of the region's most pressing coastal problems.

Critical and Emerging Science to Support Ecosystem-Based Management

South-Atlantic & Caribbean

Ecosystem Science

- Ecological connectivity between watersheds and nearshore ecosystems
- Coral reef health and function
- Climate change impacts on coastal ecosystems

Socio-Ecological Science

- Socioeconomic structures of waterfront communities
- Effects of management actions on ecosystem health and human well-being
- Recovery from catastrophic storms and adaptation to climate change impacts

Governance and Incentives

- Strategies for integrating ecosystem-level science into management objectives
- New methods to enhance communication and consensus building to achieve shared goals for sustainability and resilience

South Atlantic and Caribbean

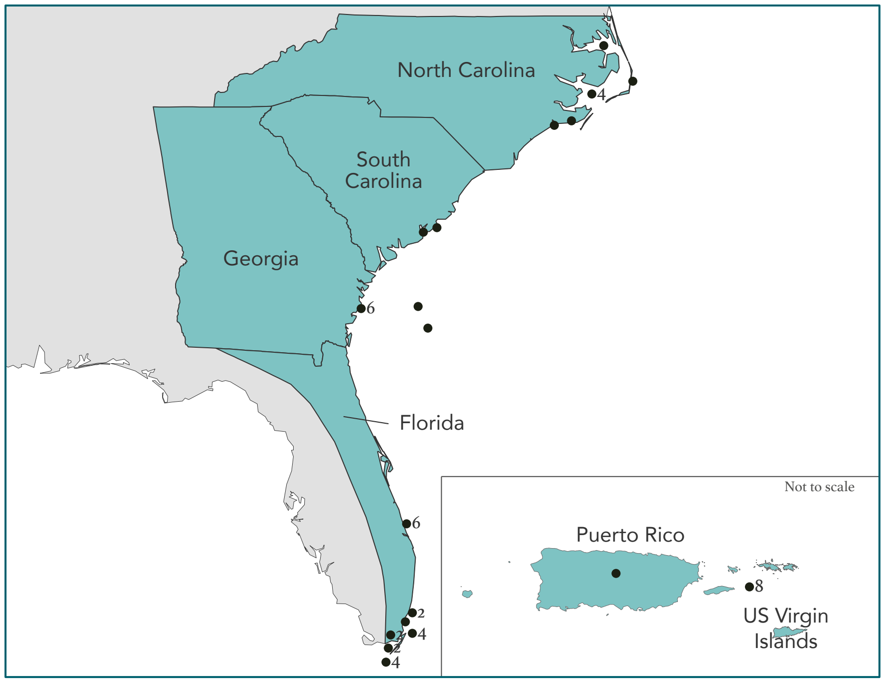


Figure 19. South Atlantic and Caribbean regions and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The South Atlantic coastal region described herein includes the nearshore state and federal waters of North Carolina, South Carolina, Georgia, and Florida. Barrier islands, estuaries, and salt marshes span from North Carolina southward to Georgia, broken up by South Carolina's sandy beaches. The waters of the South Atlantic Bight are influenced by riverine inputs and the warm northward-flowing Gulf Stream and support tropical and subtropical species.

The Caribbean region discussed here is made up of the waters surrounding southeastern Florida, the Florida Keys, the US Virgin Islands, and the Commonwealth of Puerto Rico. The tropical islands of the Virgin Islands-Puerto Rico Platform are characterized by rocky shorelines and sandy beaches. Coral reef complexes, seagrass beds, marshes, and mangrove forests are important habitats supporting biological productivity and species diversity.

Features of EBM in the South Atlantic and Caribbean

Recent research in the South Atlantic and Caribbean has evaluated the pressures and complex interactions of ecosystems to support EBM strategies (e.g., Nuttle and Fletcher 2013, Cook et al. 2014), and EBM concepts have been prioritized in regional planning documents (e.g., Governors' South Atlantic Alliance 2010, Edwards et al. 2016, South Atlantic Fishery Management Council 2018). However, ecosystem-based science application to management in the South Atlantic and Caribbean regions is behind that of some other regions. Current policies do feature elements of ecosystem-based fisheries management (EBFM), which could be considered a subsection of EBM. Fishery ecosystem plans have increasingly emphasized the need for understanding and modeling ecological connectivity (South Atlantic Fishery Management Council, 2018) and EBFM plans have been developed for both regions (NOAA Fisheries, 2019b, 2019d). EBFM strategies have made strides in integrating climate, habitat, and human dimensions into reports, assessments, and research that can lend valuable support to broader EBM goals.

Perceptions of EBM in the South Atlantic and Caribbean

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. We discuss the South Atlantic and Caribbean regions within a single chapter with recognition that there are some major differences in many aspects between the two regions. While these differences will affect the design and implementation of EBM, similar science needs emerged in our analysis when viewed from a general (high level) perspective. Following the process of the NOAA 2008 Prospectus, we present these high-level science needs together and highlight similarities and differences.

For the South Atlantic and Caribbean regions, we received 45 survey responses and conducted follow-up interviews with six of these participants. Survey respondents self-identified their roles (Table 3A) and we identified organizational affiliations from the email addresses provided in survey responses (Table 3B). Forty-two respondents agreed that EBM was a goal in their work. Of those, 28 respondents said that EBM was currently being used.

Table 3. Self-identified work titles (A) for South Atlantic and Caribbean respondents and level of organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	26
Scientist & Resource manager	4
Scientist, Resource manager, & Policy maker	2
Resource manager only	4
Resource Manager & Policy maker	3
Did not identify as above	6
Total	**45**

B.

Organization	
Federal government	5
State government	6
Non-governmental organization	3
University	8
Unidentified	23
Total	**45**

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. Two respondents described two separate locations, and one respondent described three locations, thus the results and discussion that follow describe perspectives of EBM for 49 locations.

The general priorities and views of respondents in the South Atlantic and Caribbean regions were similar to those that emerged in other regions. The majority of respondents indicated that there were important science and communication needs that, if met, would enhance the likelihood of successful EBM implementation in the region (Figure 20). Greater than half of the respondents did not agree that EBM was successfully being implemented in the locations they described (Figure 20).

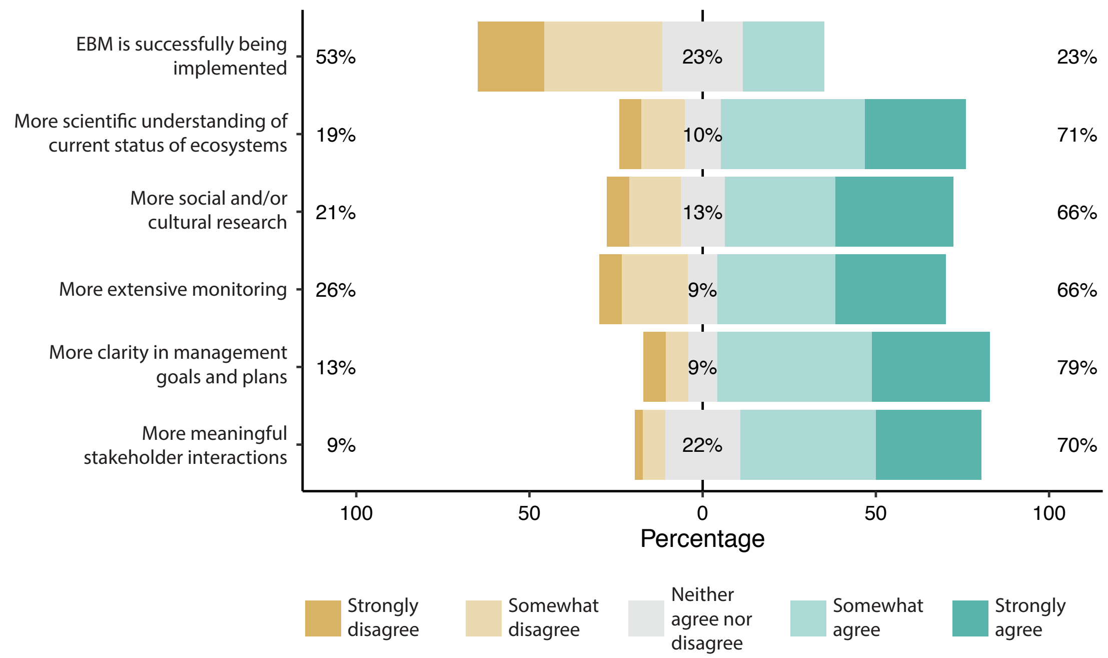


Figure 20. Practitioner opinions on needs before fully implementing EBM in locations in the South Atlantic and Caribbean (SQ12, n=48). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad environmental and socioeconomic issues in locations in the South Atlantic and Caribbean regions, *habitat integrity*, *water quality,* and *coastal resilience* were most frequently deemed very or extremely important issues (Figure 21). *Invasive species* were very or extremely important to greater than half of the survey respondents in the South Atlantic and to all 10 respondents describing Caribbean locations. In the 19 write-in responses listing additional issues that were very or extremely important for a location, the most common themes were fisheries and climate change, each mentioned in six replies (sea level rise was specifically identified five times). The addition of these topics was expected. Climate change and fisheries were considered in survey development but were not included in the list to elicit other concerns. Results of our analysis for several regions, including the South Atlantic and Caribbean, suggested that these topics were regarded by many respondents as distinct environmental concerns within EBM.

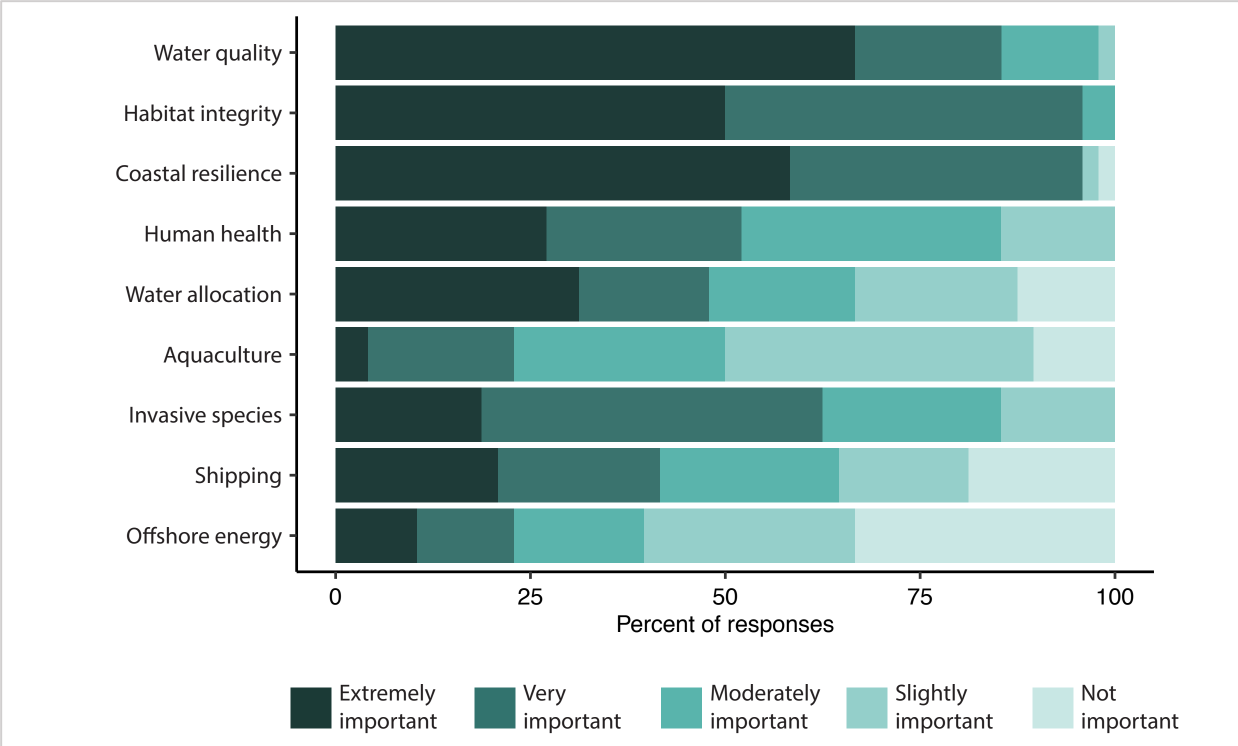


Figure 21. Priority issues as described by online survey respondents (SQ7, n=49).

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). *Implementing an interdisciplinary approach* was ranked as the most difficult element of EBM by nearly half of survey respondents (Figure 22). One interviewed resource manager in the South Atlantic believed that this could partly be explained by a lack of funding. Another respondent described governance as too inflexible to be capable of implementing interdisciplinary plans in the Caribbean region, commenting that, “In lean times, capacity to be interdisciplinary and collaborate widely is often sacrificed in favor of meeting core institutional needs.” In contrast, a responding scientist working in the US Virgin Islands ranked interdisciplinary as the easiest of the five elements of EBM, noting that because problems are large and diffuse, people are ready and willing to collaborate. The range in responses to this survey inquiry suggested that particular aspects of EBM are more feasible and realistic in some locations than others, reiterating the importance of the local component and place-based design for EBM implementation and may reveal where management has been more willing to embrace EBM concepts.

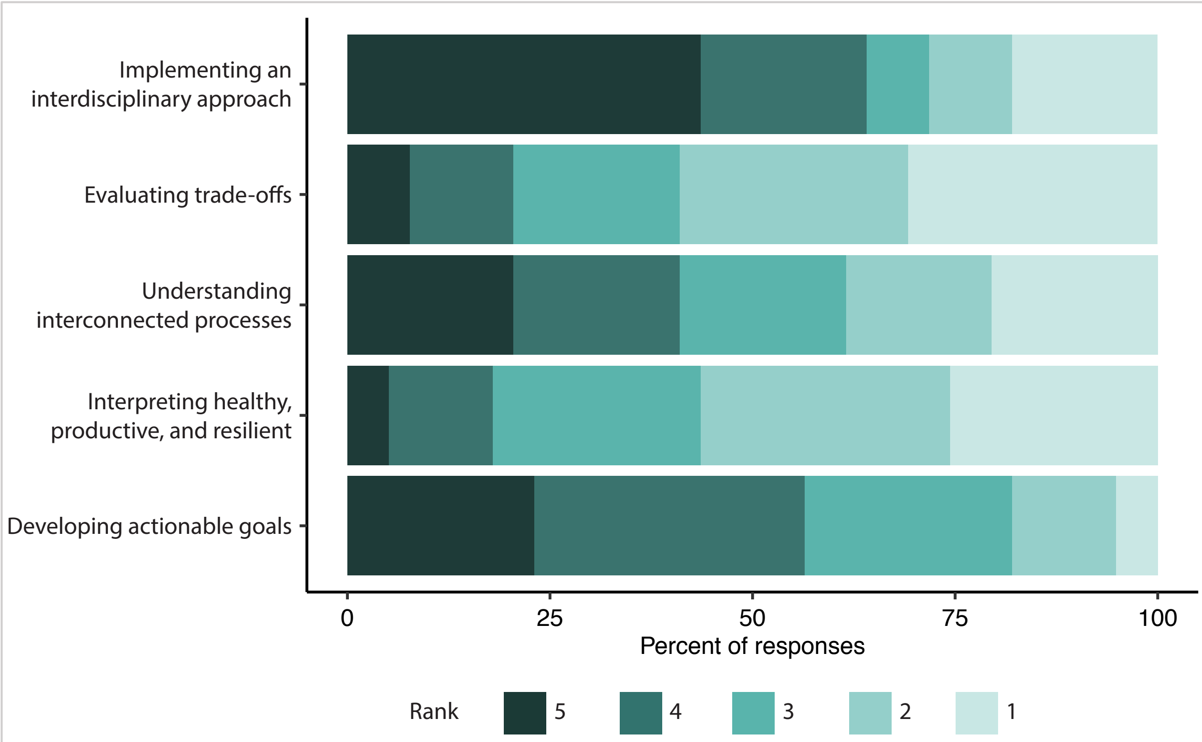


Figure 22. Perceived relative difficulty of EBM attributes where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=39).

A majority of survey participants agreed that existing *monitoring*, *data availability/databases*, and *scientific understanding of ecological linkages* as sufficient to currently support EBM planning and implementation (Figure 23). Characteristics related to management capability were more commonly perceived as hindering EBM in the Caribbean region (Figure 23B) than in the South Atlantic (Figure 23A). In follow-up comments, several South Atlantic survey respondents referred to a lack of long-term commitment (both will and resources) toward EBM. Caribbean participants added that effective communication with communities affected by management decisions would be particularly influential.

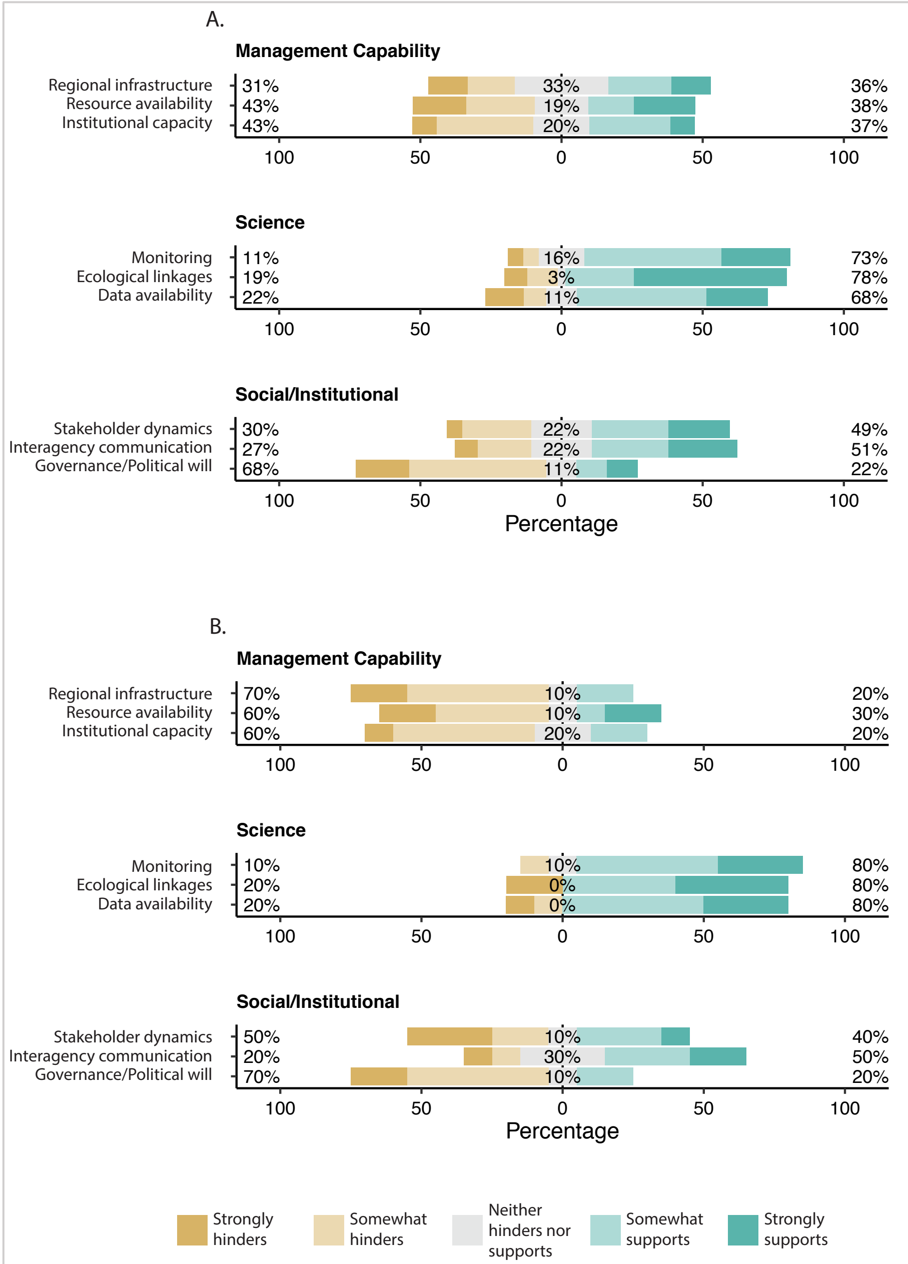


Figure 23. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11) in the (A) South Atlantic (n=37) and the (B) Caribbean (n=10).

In survey responses to the question, *What is the biggest non-science barrier to EBM?* resource commitment was the most commonly mentioned topic in both South Atlantic and Caribbean responses (Figure 24). Thirteen of 37 responses referenced a lack of funding and personnel. Political will was the second-most common EBM barrier, mentioned in 10 of 37 responses.

In interviews, we asked about perceived barriers to EBM and key elements that would enhance EBM capacity. The experiences of interviewed resource managers in both regions demonstrated that cooperation among agencies, scientists, and stakeholders was critical to EBM success. However, they also noted a lack of operational examples of EBM in the regions and the need for incentives, such as grants, personnel, and policies, to further garner support for EBM implementation. A resource manager in North Carolina said that the cycling of high-level decision makers hinders consistency toward management goals and discussed the importance of maintaining institutional knowledge. An interviewed scientist in the US Virgin Islands expressed an urgency for taking appropriate, science-based management action and developing better mechanisms for adaptive management. They noted that action delayed by the perceived need for more years of scientific observations and comprehensive evaluations of environmental response to projects will leave the coastal ecosystems unable to recover.

Figure 24. Coded themes of responses describing non-science barriers to EBM (SQ42, n=37) in the South Atlantic and Caribbean region. The size of words is relative to the frequency of the code.

Our survey asked respondents to *List the critical scientific information still needed to support or enable EBM*, which generated a wide range of ecological and social science needs that differed somewhat between South Atlantic and Caribbean responses (Figures 25 and 26). Science to better understand the risks of climate change and socioeconomic impacts of management actions (each described in seven comments) were the most common suggestions in the South Atlantic responses. The Caribbean responses were more dominated by ecological science suggestions to characterize food web dynamics (four responses) and fisheries (three responses).

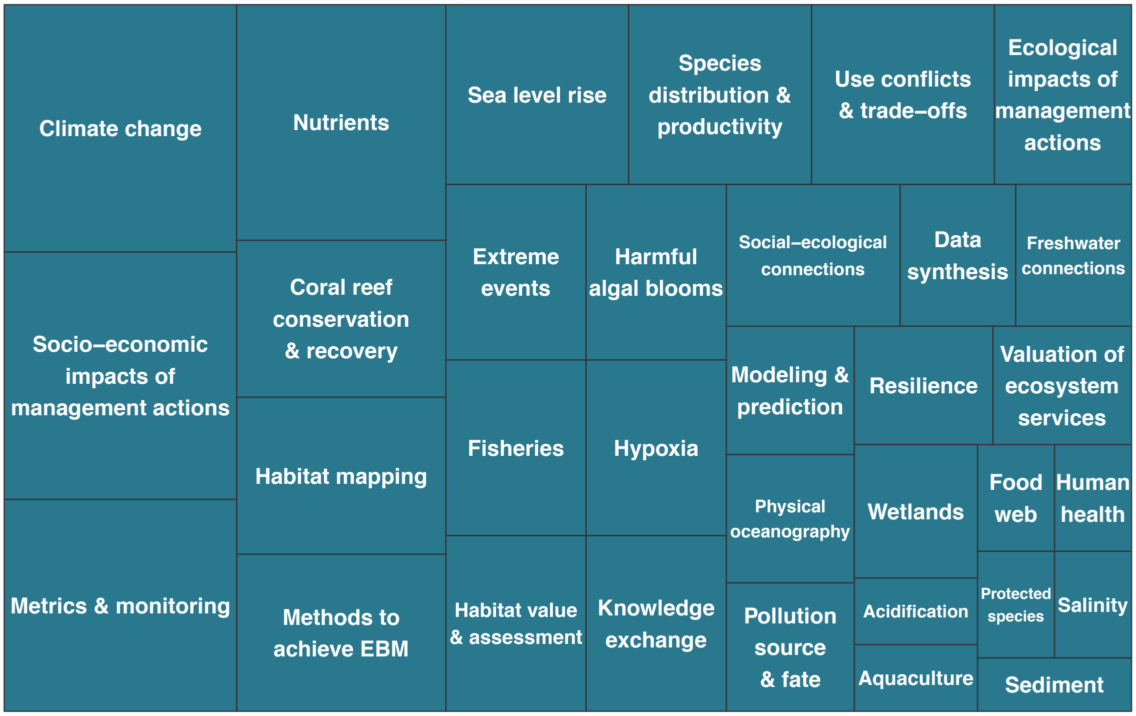


Figure 25. Topics appearing in survey responses describing critical science needs for EBM in the South Atlantic region (SQ10, n=32). Larger boxes correspond to more frequent mentions.

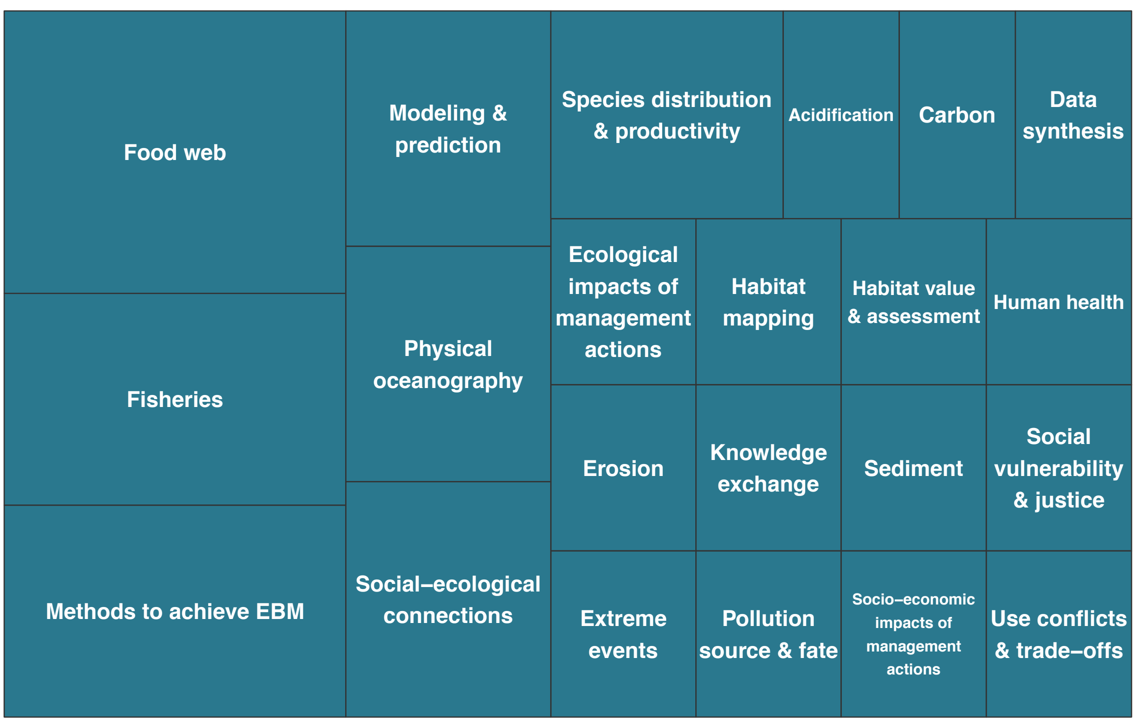


Figure 26. Topics appearing in survey responses describing critical science needs for EBM in the Caribbean region (SQ10, n=10). Larger boxes correspond to more frequent mentions.

Critical and Emerging Science to Support EBM in the South Atlantic and Caribbean Regions

One of the purposes of this project was to provide an update to the Regional Ecosystem Research Prospectus (2008 Prospectus), a document that has helped guide regional coastal science research to address EBM and other management needs (NOAA National Centers for Coastal Ocean Science 2008). Broad research priorities presented in the 2008 Prospectus for the South Atlantic and Caribbean regions included characterizing ecosystem vulnerability to human and environmental disturbances, including impacts from hurricanes, tourism, coastal land use, and sea level rise. The guide further suggested science to improve understanding of estuarine habitats and interconnections with the regional ocean circulation and how changes may influence local and regional socioeconomics.

Ecosystem Science

Survey responses and regional reports described a need for ecosystem-level science that improves the characterization of the current status of ecosystems to improve understanding and provide a basis for anticipating the future effects of change on the ecosystems of the South Atlantic and Caribbean regions. Ecosystem science is needed to understand the cumulative impacts of climate change and coastal development on habitat structure and function, and how these effects on ecosystems affect the provisioning of ecosystem services (Governors' South Atlantic Alliance, 2010). Planning and implementation documents also acknowledged the need to consider options of how to better incorporate ecosystem-level information into management (e.g., Nuttle and Fletcher 2013b, NOAA Fisheries 2019b). A survey respondent suggested that the research scope used to for management needed to be refined to improve effectiveness.

ES 8. Ecological connectivity between watersheds and nearshore ecosystems

The specific research suggestions provided within the top categories of habitat integrity and water quality in both regions were about controlling the export of materials from land. Respondents' recommendations included research to better characterize the effects of land use in the watershed on estuarine water quality and habitat integrity, such as loads and speciation of nutrients, sediment sources, and emerging contaminants. These needs were expressed across many respondents, with examples of specific concerns being source control for stormwater runoff and vulnerability of seagrass and fish communities to changes in water quality.

The 2008 Prospectus similarly described a need to better understand land-sea linkages in the South-Atlantic and Caribbean regions (NOAA National Centers for Coastal Ocean Science, 2008). A related research concern that emerged in our review of the regional literature was to describe interdependencies between freshwater quality and quantity and estuarine and coastal wetland habitats in order to preserve important ecosystem services (Laporte et al., 2011; South Carolina Sea Grant Consortium, 2019). Regional plans also described the need for habitat mapping and ecosystem characterization to understand current status and trends of habitat availability and ecosystem health (Laporte et al., 2011; NOAA, 2014).

Illustrative examples of science needs related to ecological connectivity identified in surveys and planning documents were:

- Local-level understanding of the roles of watershed characteristics (e.g., pollutants, stormwater) and water residence times on sestonic algal productivity (affecting light availability for submerged aquatic vegetation) and harmful algal blooms (e.g., Indian River Lagoon, Pamlico Sound)
- Watershed and shoreline influences on seagrass habitat integrity and coverage
- Opportunities for innovation in sediment control solutions (engineered or natural) in river basins to reduce sediment influx to estuaries
- Vulnerability of marsh and estuarine habitats to the effects of variation in freshwater quantity and quality and how freshwater delivery depends on watershed characteristics and its management
- Beneficial use of sediment for ecological restoration and resilience (e.g., thin-layer placement in marshes, barrier island restoration)

ES 9. Coral reef health, function, and resilience

Coral reef health was a concern for respondents describing locations in the deep-sea coral ecosystems off the coast of South Carolina, the barrier reef tract of the Florida Keys, and the fringing reefs of Puerto Rico the US Virgin Islands. The effects of ocean chemistry and temperature change on reef systems were the predominant science need appearing in survey responses and in many regional planning documents. Climate change is among the most serious threats to coral reef ecosystems (NOAA, 2014). Regional plans and strategies also encouraged science to help understand and address watershed pressures on corals, such as nutrient and sediment runoff (e.g., NOAA National Centers for Coastal Ocean Science 2008, Sturm et al. 2014, Sea Grant Puerto Rico 2018). Survey respondents also noted a need for a better understanding of the effectiveness of watershed actions to reduce nutrient and sediment impacts on reefs and improved coordination of local and regional watershed management. Other survey comments noted science needs to better decipher the mechanisms of the causes of coral disease and recovery. For example, stony coral tissue loss disease, first documented in 2014, is an increasing threat causing rapid die-offs in multiple species in the Florida Reef Tract and expanding throughout the Caribbean region, suggesting the need for a coordinated management response (Doyle and O’Sullivan, 2019).

Research is also needed to better understand tourism's impact (e.g., recreational fishing, land development, marine debris) on sensitive reef structures and their associated biological populations and ways to protect the reefs, while still providing the socioeconomic benefits of visitation (e.g., ecotourism alternatives). There are significant challenges for management to achieve conservation goals in reef systems where human pressures are greater, and local prioritization is essential to setting realistic management goals (Cinner et al., 2020).

Examples of science related to coral reefs in the South Atlantic and Caribbean regions were:

- Impacts on corals of multiple simultaneous stressors, including acidification, slowing Gulf Stream, and changes in temperature regime (e.g., upwelling events and heatwaves)
- Effects of watershed sediment and nutrient supply to reef systems (e.g., light limitation related to increased sestonic algae concentrations), including effects of mitigation actions (e.g., potential benthic smothering with beach replenishment projects)
- Identification and evaluation of potential management-based intervention strategies to encourage reef recovery from disease and bleaching events
- Determination of the environmental factors influencing the spread of invasive species on reefs, the ecosystem effects of such invasions, and effective methods of response
- Description and mapping of deep-water coral ecosystems off the southeastern US continental shelf to reduce uncertainties about their distribution and status
- Effective reef restoration strategies (e.g., harvesting, growing, outplanting)

ES 10. Climate change impacts on coastal ecosystems

The need for research to understand the influences of climate change on trophic interactions and critical habitats were expressed by survey respondents, in follow-up interviews, and in regional science strategy documents. The coastal marine zone of southeastern Florida to the Florida Keys is a transitional region where the waters of the Caribbean, Gulf of Mexico, and Atlantic Ocean are hydrologically and biologically linked (NOAA National Centers for Coastal Ocean Science, 2008). Research is needed to better understand and quantify the ecosystem-level impacts of climate-related disruptions in trophic interactions (South Atlantic Fishery Management Council, 2018) and to anticipate the influence of climate change on species ranges, migration routes, and reproductive dynamics and success (e.g., Laporte et al. 2011, NMFS 2014).

Survey participants encouraged science that could support the development of predictive models of ecological productivity and that are capable of quantifying (to the extent possible) habitat resiliency. Evaluation of sea level rise impacts on ecosystem health, particularly wetlands, was a common suggestion for new science to support EBM strategies in the South Atlantic region. Research is needed to identify ecosystem thresholds relevant to understanding risk and capacity to increase resilience in current systems in support of EBM (APNEP, 2012). This will necessarily include a focus on wetland responses to changes in the magnitude and timing of freshwater and sediment supplies and seawater inundation.

> "Building resilience into an ecosystem means working to support the health and function of associated habitats, organisms, and ecosystem processes."
>
> -Reef Resilience Network

Respondents also expressed a need for evaluation of the effects of extreme events on coastal habitats and fisheries. With climate change causing more frequent and intense tropical storms in the regions, managers of both mainland and island environments will need to understand the acute effects of storms and the resulting trajectories of ecosystem recovery. For example, hurricane impacts to coral reefs include immediate physical damage as well as near-term ecological injury from storm-related sediment and pollutant runoff (Edmunds et al., 2019). Many of these ecosystems are already vulnerable because of anthropogenic effects and coral disease and may be unable to recover (Kobelt et al., 2020).

The following examples of research topics illustrate the types of science related to ecosystem effects of climate change that would further support EBM strategies in the regions:

- Acute effects of extreme weather and climate events on ecosystems, habitats, and fisheries (e.g., hurricanes, flooding, hypersalinity, physical damage to coral)
- Changing Gulf Stream dynamics and the anticipated effects of its northward shifting on species distributions, phenology, and productivity, with special emphasis on protected species

- Identification of climate change factors most significant to benthic functioning and trophic interactions (including shellfish population dynamics and impacts to aquaculture)
- Prediction of marsh migration capabilities and the potential impacts and solutions when migration range is limited by land use
- Sea level rise effects on wetlands (e.g., peat decomposition, accretion, and carbon storage) including their role in improving the quality of water flowing to estuaries and potential for mitigating climate change impacts

Socio-Ecological Science

The need for social science research was expressed repeatedly in survey responses, follow-up interviews, and planning documents for the South Atlantic and Caribbean regions. The survey comments and regional and local reports illustrated a need for socio-ecological research into how individual perspectives, community norms, and institutional structures (regulations, market dynamics, and social pressures) create barriers and opportunities for EBM. Responding scientists, resource managers, and policy makers noted gaps in understanding of the human dimensions of EBM and how decision making could better reflect the regional identity and socioeconomic priorities. Rich cultural and social structures generate diverse local coastal identities and unique sense of place in communities that must be understood to effectively manage systems and

Ciguatoxins in Coral Reef Fishes

Ciguatoxins are produced by benthic microalgae and can bioaccumulate in tropical reef fish. Contaminated fish can cause Ciguatera fish poisoning (CFP), a common food-borne illness from fish consumption, though prevalence can be reef-specific. CFP presents with gastrointestinal and neurological symptoms that can last for weeks to months. Concerns and uncertainties related to CFP can also have local economic impacts and reduce the commercial value of harvested species such as snapper and grouper. There is need to explore how ciguatoxins travel through the food web and to develop an efficient method of determining toxicity.

The 2008 Prospectus also noted a need to better understand trophic transfer dynamics of Ciguatoxins in the South Atlantic and Caribbean regions. Incidence of CFP occurs at a level of high concern, though it is likely that only a fraction of cases are reported. Effective response to CFP concerns is limited by knowledge gaps about how to detect ciguatoxins in commercial fish species and prevent presence in the food supply. Rising water temperatures due to climate change are expected to increase incidences of CFP.

Sources: NOAA National Centers for Coastal Ocean Science 2008, Tester et al. 2010, Friedman et al. 2017, IPCC 2019, Soliño and Costa 2020.

maximize well-being. Respondents in both regions expressed a need for crosscutting science to identify how to best integrate policies among economic and community sectors to effectively restore systems. Another interviewed respondent said that identifying incentives that are effective at changing behaviors is a key ingredient to achieving EBM. A responding scientist and resource manager in the Caribbean highlighted a need for regional collaboration in resource management and research to enhance social justice and local livelihoods. Additional socio-ecological science is needed to reveal the links between people and their environments and how information on these linkages can then inform and enhance EBM implementation.

SES 7. Socioeconomic structures of waterfront communities

Survey responses suggested a need to better characterize local communities (e.g., cultural identities and perceptions of shifting resource use and availability) in order to enable more effective and equitable decision-making that promotes social well-being and sustainability. Regional planning and strategy documents also prioritized socio-ecological science to quantify the value of healthy ecosystems in terms of socioeconomic benefits to local communities (Laporte et al., 2011; South Carolina Sea Grant Consortium, 2019). Economies in both regions rely on tourism and recreation, cargo ports, commercial fisheries, and other marine businesses. Respondents called for more integration of social science into the decision-making process and social indicators are needed to implement and assess progress on EBM strategies (NOAA Fisheries, 2019d).

Some examples of the science needs in this category that could be used to increase integration of social factors into planning and implementation strategies were:

- Cascading effects of habitat loss (and gains under restoration) on regional and local economies and community identity
- Economic, social, and cultural values of improved water quality
- Documentation of the changing social and cultural structures of working waterfront communities, including community perceptions of aquaculture and its feasibility
- Development of socioeconomic metrics of community health and well-being
- More comprehensive valuation of the ecosystem services provided by wetlands, barrier islands, and reefs

SES 8. Effects of management actions on ecosystem health and human well-being

Social and economic impacts of management actions (and inaction) were among the most frequently suggested research needs to enhance EBM (Figures 25 & 26). This concern was echoed in fisheries implementation plans that prioritized the development and ground-truthing of social indicators designed to evaluate the effects of fishery management by tracking community well-being (NOAA Fisheries, 2019d, 2019b). Science to describe the ecological effects of management actions was also suggested by respondents and regional planning documents. A resource manager working in coastal North Carolina said that they believed they were doing a poor job of tracking the effects of management actions on the environment, partly because of a lack of resources (monetary and personnel) to support data translation into a management-ready format. Research to evaluate the effectiveness of restoration actions targeted at restoring ecosystem function is a priority in the South Atlantic (Laporte et al., 2011). Survey responses and regional planning documents expressed a need for efficient monitoring to track impacts and progress of management actions and inform adaptive management (e.g., APNEP 2012, Sturm et al. 2014).

The following examples of specific science needs were derived from surveys and regional documents:

- Effectiveness of fisheries management and regulations in preventing overfishing in the Caribbean region, including evaluating enforcement methods
- Influences of shoreline modification (e.g., hardening, replenishment) on the integrity, accessibility, and quality of terrestrial, beach, wetland, and transitional habitats
- Development of methods and indicators to measure ecosystem responses to management actions in the short and long term (e.g., effectiveness of stormwater management for reducing pollutants entering waterways, efficiency for monitoring decadal-scale responses of habitat restoration)
- Tools for assessing the cumulative effects of management actions (projects or policies) affecting coastal natural resources at local and regional scales and to determine the overall capacity for mitigating increasing stressors (e.g., climate change, population increase)

- Aquaculture feasibility and siting in terms of ecological productivity, economic feasibility, and social acceptance
- Evaluation of the distribution of costs and benefits of potential management actions and tradeoffs of inaction

SES 9. Recovery from catastrophic storms and adaptation to climate change impacts

Climate change adaptation was among the top priorities for new research cited in the survey responses. Science needs were related to both human and ecosystem responses to climate change impacts and were particularly focused on predicting sea level rise and resource availability changes (e.g., fisheries and water supply) and human responses to risk. For example, one interviewed scientist and resource manager in Puerto Rico recommended more social science research to learn the reasons people choose to stay and rebuild after catastrophic storms. They noted that this is true of both poor and middle-class communities in the Caribbean. Catastrophic storms can also displace people, altering social structures and impacting cultural heritage and local ecological knowledge (Boger et al., 2019). Characterization of vulnerable communities to support equality in management, resilience, and recovery strategies is a need in both regions.

Specific science examples to address coastal community adaption included:

- Economically efficient and equitable management strategies to allocate a changing freshwater supply impacted from saltwater intrusion, storm impacts, and drought
- Elucidation of psychological, cultural, and other community factors that govern individuals' responses to sea level rise risk and use of this information to design effective strategies for overcoming inaction or community reticence to accept hazard mitigation plans
- Social and cultural characteristics of the most vulnerable coastal communities to understand opportunities for resiliency adaptation (e.g., retreat or rebuild with regard to environmental equality and social identity)
- Effectiveness of nature-based solutions to shoreline change and floodplain management

- Methods to prioritize conservation of types and locations of natural ecosystems that provide cost-effective resilience

Governance and Incentives

Survey respondents commonly referenced the need for improvements in governance and communication when describing science needs in the South Atlantic and Caribbean regions. A scientist working in South Florida also acknowledged that there was much room for better packaging and communication of science to management. Two major themes for new science to support EBM implementation that emerged from our analysis were social science research to identify incentives that motivate human behavior change (both within and outside of managing institutions) and more effective translation of science to management actions.

> "The time has come to think about things in a different way, with EBM principles."
>
> -Responding Resource Manager

To improve EBM capacity and implementation in the South Atlantic and Caribbean regions, our analysis suggested a need for research to understand what effectively motivates individual behavior change, including economic incentives, rewards and public recognition, and social marketing. Research is also needed to address governance shortcomings and support effective strategies for changing institutional structure and performance measures in ways that promote cooperative problem solving within and among agencies and with regulated parties in order to remove barriers to cost-effective restoration and innovation.

GI 7. Strategies for integrating ecosystem-level science into management objectives

Regional documents suggested a need for science that would support innovative management procedures (e.g., ways to build effective partnerships) and analytic methods (e.g., improved interpretation of science relevant to management objectives) to make monitoring and research results more accessible to decision makers for more holistic and adaptive approaches to management. Given the relative lack of regional EBM examples in coastal management (also noted by several survey participants) and the varied ecosystems and their incompletely understood interconnections in the South Atlantic and Caribbean regions, it is understandable that there are still knowledge gaps regarding how institutions and agencies can pursue these more holistic approaches.

Examples of research directions to support EBM in this category were:

- Identification of types of benefit measures (monetary values, benefit-relevant indicators, ecosystem service quantities) that would be most useful for decision makers
- Effective methods for translating science for use in management and policy decision making, including monitoring and analyses to evaluate the effectiveness of science-based actions already in place
- Development of new methods to enhance communication and consensus building to achieve shared goals for ecosystem sustainability across institutions
- Strategies to improve the efficiency of monitoring and data evaluation and successful application to adaptive management

GI 8. New methods to enhance communication and consensus building to achieve shared goals for sustainability and resilience

Science to support the understanding of ecosystem resilience to climate change effects was a common suggestion in survey responses and regional strategic plans. Better characterization of ecological vulnerability is expected to improve regional planning and enable adaptive management and implementation of mitigation strategies (Governors' South Atlantic Alliance, 2010). However, there is evidence that the consensus support needed for effective implementation of these strategies will vary widely across locations within both regions. Many regional planning documents, and several survey respondents, promoted public outreach and stakeholder involvement to encourage behavior change. However, communication campaigns such as those describing risks associated with climate change may not always have the expected impact (e.g., Dixon et al. 2019, Palm and Bolsen 2020). More effective use of social science including environmental psychology, anthropology, and behavioral economics has potential to contribute to innovative and effective approaches to contending with climate change impacts in the South Atlantic and Caribbean regions.

The dynamic coastal environments of the Caribbean islands are particularly vulnerable to projected weather and sea level conditions because of the density of infrastructure in hazardprone areas and the limited land area available for retreat. Because tourism and recreation are major economic contributors to the South Atlantic and Caribbean regions, social well-being is vulnerable to harmful algal blooms, sportfish declines, coral reef degradation, and other changes that negatively impact the recreational values of the ecosystems.

- New strategies to enhance communication and consensus building to achieve shared goals for ecosystem sustainability across stakeholders and communities
- New methods for identifying and quantifying the social benefits of restoration and conservation actions in coastal systems at the local and regional scales
- Social science research to reveal and test the effectiveness of incentives for encouraging individual and institutional change (e.g., governance toward EBM, potential for alternative livelihoods)

CONCLUSION

Respondents in both regions suggested the need for greater commitment to EBM (including financial and personnel resources) from local and regional leadership and management institutions. The resource managers and scientists working in the South Atlantic appeared to recognize the potential for EBM to improve coastal resources management but noted that many regional decision makers were only just beginning to accept EBM as a useful strategy. Those we encountered working in the Caribbean region described local management institutions as eager for EBM, but limited financial resources hinder the development of cross-cutting science and tools to effectively implement EBM.

The research examples named throughout this chapter were envisioned to support EBM implementation in the interconnected South Atlantic and Caribbean regions. New knowledge will be essential for understanding the challenges and opportunities for ensuring resilient ecosystems and human communities. Key concerns common to the South Atlantic and Caribbean regions included the multiple interacting effects of greater populations and development on the coastal ecosystems that are increasingly vulnerable to sea level rise and storms, and the socioeconomic impacts resulting from ecosystem change. Our synthesis determined a critical need for science to characterize the dynamic interconnections within and among ecosystems of the South Atlantic and Caribbean. This new knowledge will support predictive tools and more cooperative approaches to enable and enhance EBM.

Critical and Emerging Science to Support Ecosystem-Based Management

Gulf of Mexico

Ecosystem Science

- Ecological responses to changing coastal habitats
- Ecosystem connectivity pathways and processes
- Ecosystem vulnerability to multiple ocean uses

Socio-Ecological Science

- Effects of catastrophic events and methods to enhance management response
- Coastal community adaptation to sea level rise
- Socioeconomic impacts of restoration and conservation actions

Governance and Incentives

- Strategies to support systems-level perspectives in fisheries management
- Ecological resilience links to human community well-being

GULF OF MEXICO

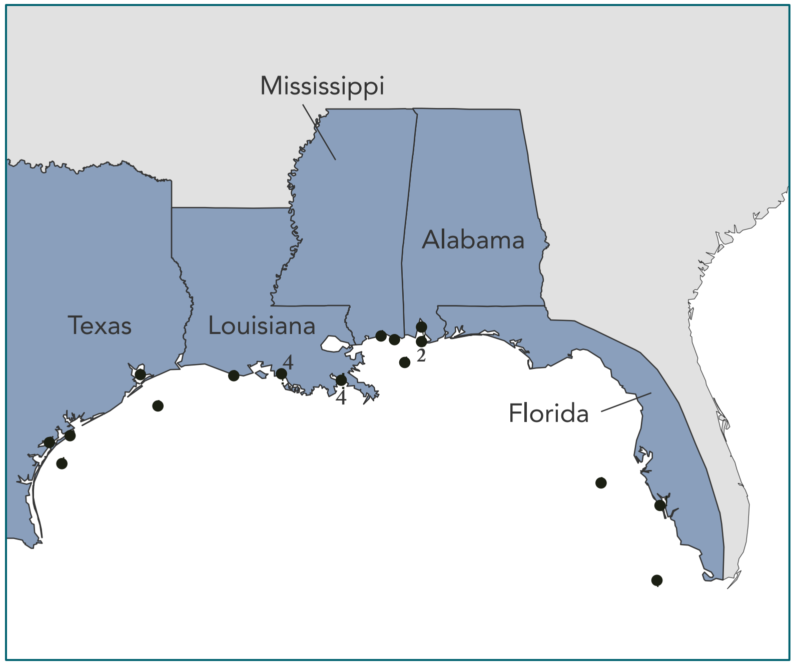
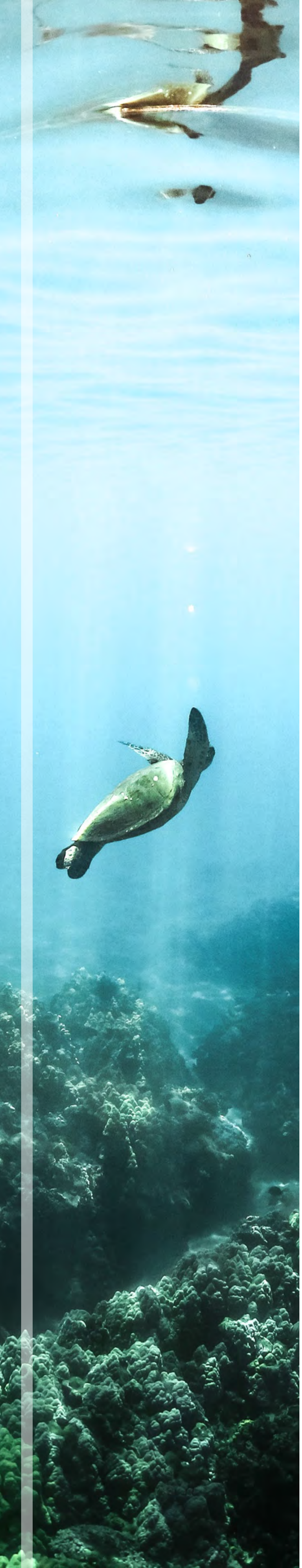


Figure 27. Gulf of Mexico region and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The Gulf of Mexico region described herein includes the coastlines of Alabama, Louisiana, Mississippi, Texas, and the western coast of Florida and extends past the coastal shelf and into the deep waters of the northern Gulf of Mexico Basin. Habitats include lagoons, estuaries, freshwater and saltwater wetlands, deltaic systems, barrier islands, and reefs. A dominant feature in the region is the Mississippi River/Atchafalaya River Basin, draining greater than 40% of the contiguous US, providing freshwater, nutrients, and sediment to the northern Gulf of Mexico.



Features of EBM in the Gulf Of Mexico

Management of natural resources in the coastal, shelf, and oceanic zones of the Gulf of Mexico region has historically been focused on single issues and stressors and the economic, environmental, and ecological benefits and costs associated with management actions designed to ensure sustainable use of the natural resources. Over the last two decades, the need for a more holistic approach has been realized to manage for the complexities of the Gulf of Mexico human-environmental system. The Deepwater Horizon oil spill highlighted the need for a more ecosystem-based approach to understanding the physics, ecology, economics, and people and community aspects of the Gulf of Mexico, and generated funds leading to multiple efforts to advance the natural and social sciences in the Gulf (e.g., NOAA's RESTORE Science Program, Gulf Research Program, Gulf of Mexico Research Initiative, RESTORE Centers of Excellence). Though not explicitly stated as such, the Gulf Research Program has developed a Strategic Vision Document (National Research Council and Citation, 2014) that is suggestive of an EBM strategy and may help make strides to advance EBM activities in the region.

NOAA's Integrated Ecosystem Assessment program has been working toward EBM and EBFM in the Gulf of Mexico. The Gulf Ecosystem Status Reports (Karnauskas et al., 2013, 2017) have been a valuable tool for encouraging a more systems-level approach to natural resource management in the region. Methods for achieving EBM in the Gulf of Mexico have been increasingly explored (e.g., Yáñez-Arancibia et al. 2013, Oakley et al. 2018) and a comprehensive EBM strategy for the region was encouraged by the National Ocean Council (Gulf Coast Ecosystem Restoration Task Force, 2011). The Gulf of Mexico's ecosystem-based science is behind that of some other regions (but ahead of others) in terms of readiness for implementation. However, current policies do feature elements of EBFM, which could be considered a subsection of EBM (e.g., NOAA Fisheries 2019).

Perceptions of EBM in the Gulf of Mexico

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Gulf of Mexico region, we received 31 survey responses and conducted follow-up interviews with three of these participants. Survey respondents self-identified their roles (Table 4A) and we identified the level of organizational affiliation from the email addresses provided in survey responses (Table 4B). Thirty respondents agreed that EBM was a goal in their work and that they provide guidance for management decisions. Twenty-one respondents said that EBM was currently being used, and the remaining 9 responded that it was not yet being used in their work.

Table 4. Self-identified work titles (A) for Gulf of Mexico respondents and organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	18
Resource manager only	2
Scientist & Resource manager	2
Policy maker only	1
Did not identify as above	4
Total	**31**

B.

Organization	
Federal government	6
State government	1
Non-governmental organization	2
University	5
Unidentified	17
Total	**31**

The general priorities and views of respondents in the Gulf of Mexico region showed some similar patterns as in other regions. The majority of respondents indicated that there were important science and communication needs that, if met, would advance the likelihood of successful EBM implementation in the region (Figure 28). Fifty-nine percent of respondents disagreed that EBM was successfully being implemented in the locations described (Figure 28).

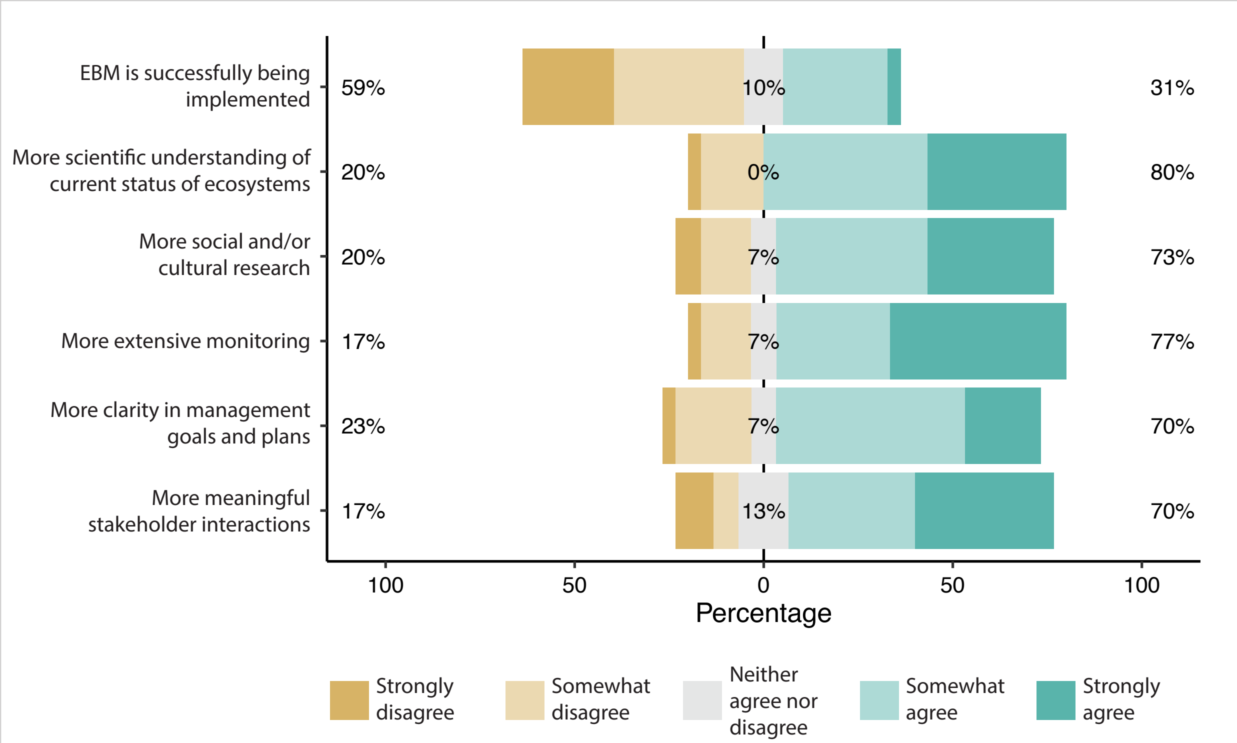


Figure 28. Practitioner opinions on needs before fully implementing EBM in locations in the Gulf of Mexico (SQ12, n=31). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad issues in the Mid-Atlantic region, *water quality*, *habitat integrity*, and *coastal resilience* were most commonly rated as very or extremely important issues (Figure 29). In responses to the option to provide additional issues deemed very or extremely important for their location, fisheries topics were the most common write-in, noted in 6 of the 18 responses. We expected to see the subject of fisheries in these responses as EBFM is an existing effort in the region. We did not explicitly list fisheries in the survey to encourage other less prevalent issues. Results of our analysis for several regions, including the Gulf of Mexico, suggested that fisheries were regarded by many respondents as a distinct environmental concern within EBM, while also recognizing that fisheries issues within EBM are interwoven with many of the other issues on our list.

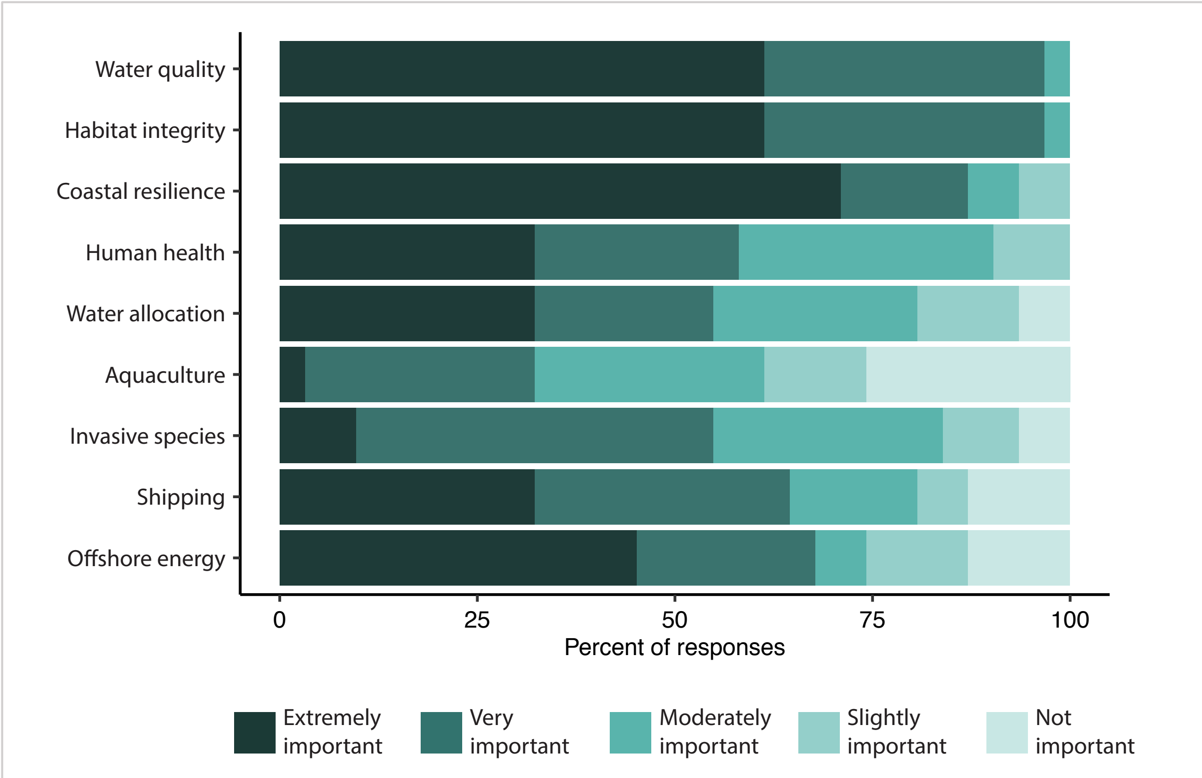


Figure 29. Priority issues as described by online survey respondents (SQ7, n=31).

> "Knowing it needs to be conserved is easy, convincing others is different."
>
> – Responding Resource Manager

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). Nearly half of survey respondents ranked *implementing an interdisciplinary approach* as the most difficult aspect of EBM to achieve (Figure 30). Another difficult element of EBM, according to respondents, was *evaluating tradeoffs, including understanding risk and uncertainty*. These tradeoffs are already present but often not explicitly dealt with in single-issue management. One interviewed respondent noted that tradeoff consideration is when competing interests enter the discussion and it becomes more difficult to come to a consensus about policy or management action. EBM has the advantage of bringing clarity to these tradeoffs.

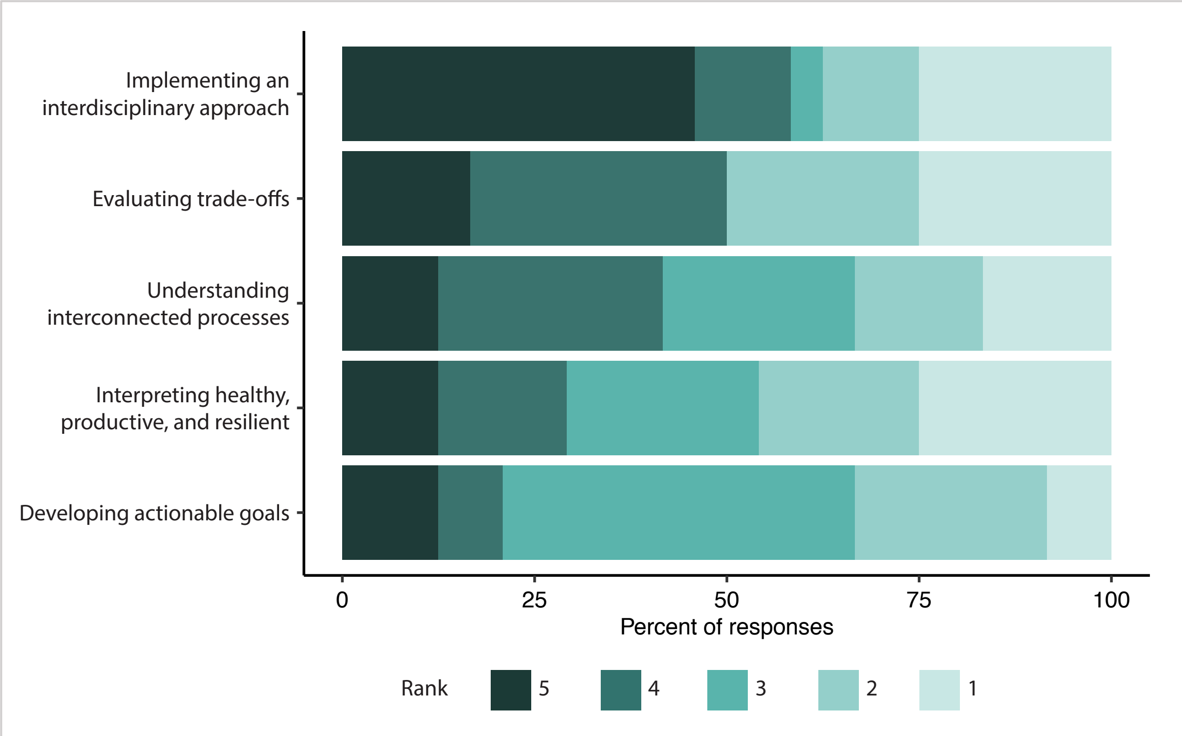


Figure 30. Perceived relative difficulty of EBM attributes, where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=24).

When asked to rate the influence on EBM (either supporting or hindering) of a list of management characteristics, the majority of online survey respondents agreed that scientific understanding of ecological linkages and sufficient monitoring support an EBM approach, and that institutional mechanisms and political dynamics are hindering EBM planning and implementation, even when solid natural science is available (Figure 31). Similar sentiments were expressed in response to, *What is the biggest non-science barrier to EBM?* Eighteen of the 24 responses referenced institutional characteristics or resource commitment (Figure 31). One federal-level manager expressed the belief that the science is making it to the managers, but the "weakest link" for EBM is that the science is not particularly useful for informing management decisions. Several sources also suggested that, philosophically, many managers are on board with an EBM approach – the difficulty has been in engaging the politicians. In examples of where EBM has made some progress, political backing was cited by interviewed respondents as most critical. It appeared that the recent influx of financial resources released from the Deepwater Horizon settlement has helped policy makers and managers make headway with EBM.

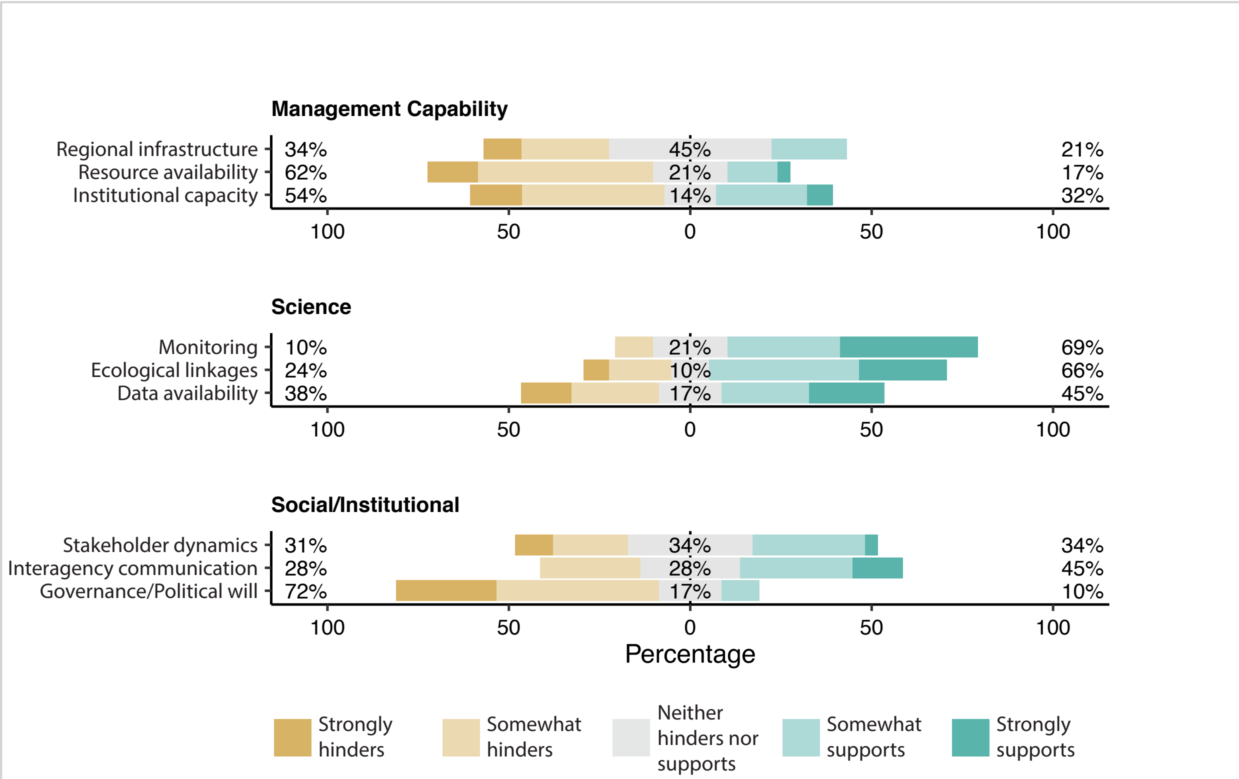


Figure 31. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11, n=28).

Figure 32. Coded themes of responses describing non-science barriers to EBM (SQ42, n=24) in the Gulf of Mexico region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. The most frequent science needs that were described in responses in the Gulf of Mexico region were related to understanding and anticipating future impacts of management actions and scenarios. Improving understanding of the socioeconomic impacts of management actions (8 of 26 comments) and identifying conflicting uses and tradeoffs for decision making (7 comments) were the most common themes identified in descriptions of critical science (Figure 33). Responses related to ecological impacts of management, fisheries, and food webs were each described in 6 responses.

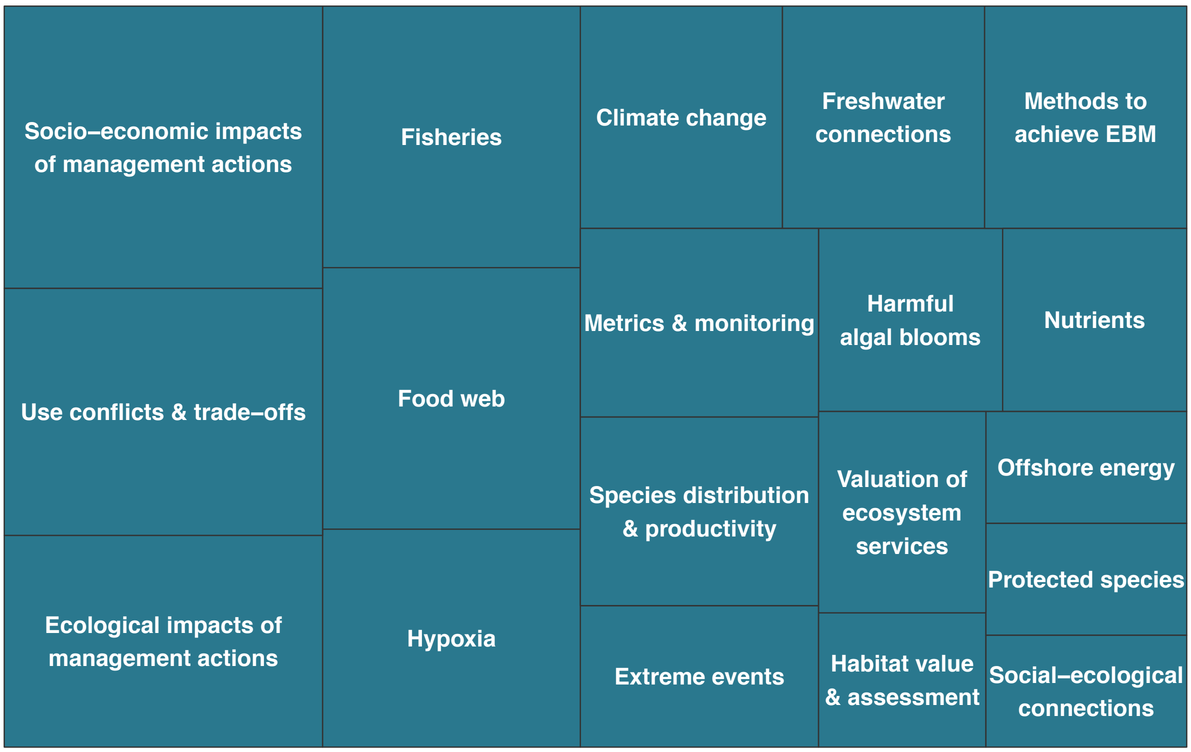
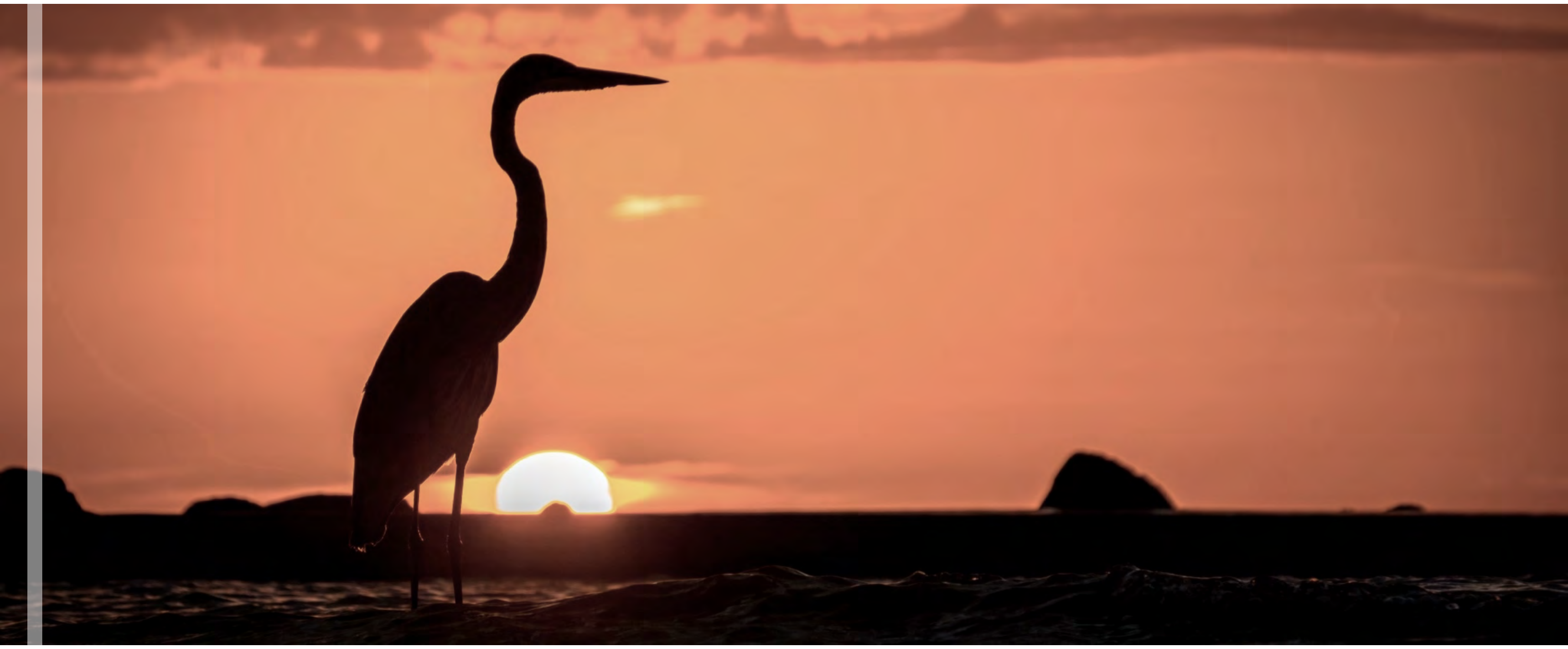


Figure 33. Topics appearing more than once in survey responses describing critical science needs for EBM in the Gulf of Mexico region (SQ10, n=26). Larger boxes correspond to more frequent mentions.

Critical and Emerging Science to Support EBM in the Gulf of Mexico Region



One of the purposes of this project was to provide an update to the 2008 Prospectus, a document that has helped guide regional coastal science research to address EBM and other management needs (NOAA National Centers for Coastal Ocean Science 2008). Broad research priorities for the Gulf of Mexico presented in the 2008 Prospectus included ecosystem and human health effects of harmful algal blooms, fate and transport of pollutants, and determination of optimal harvest levels and threats to protected species under multiple stressors. The guide further described the need for coupled landscape and aquatic system modeling. This effort updates and expands upon those recommendations.

Ecosystem Science

Survey responses and regional reports both described a need for new ecosystem science to better understand coastal change in the Gulf of Mexico. The 2008 Prospectus defined needs for research to understand the effects of individual stressors on specific uses and habitat types (NOAA National Centers for Coastal Ocean Science, 2008). More recent priorities described in regional planning documents and by survey respondents were focused on understanding ecosystem connectivity across habitats and regions (e.g., estuary-shelf exchange of material, pelagic-benthic coupling of energy transfer) and cascading effects of change whereby, for example, a perturbation in habitat or one component of the food web triggers a complicated set of responses in other components. Research gaps also exist concerning how physical changes to the coastal environment combine with continued development to affect the ecology and ecosystems of the Gulf (National Academies of Science Engineering and Medicine, 2018).

ES 11. Ecological responses to changing coastal habitats

A Gulf of Mexico resource manager responded that habitat integrity is the single most important issue in the Gulf of Mexico and described a need to better predict ecological changes occurring in the nearshore coastal area to inform decision-making. Nearshore habitat change driven by climate change and anthropogenic activities was a common research priority in regional planning and strategy documents (e.g., Gulf Coast Ecosystem Restoration Task Force 2011, Gulf of Mexico Alliance 2016, Lovett et al. 2016). The importance of nearshore environments in this region cannot be overstated. Coastal habitats play significant roles for flood protection, carbon sequestration, erosion control, water quality, and provide essential habitat for aquatic and terrestrial species. Nearly all of the commercial fish and shellfish caught in the Gulf of Mexico depend on the region's estuaries and coastal wetlands during at least some portion of their life cycle (Gulf of Mexico Alliance, 2016). Gulf of Mexico barrier islands are critical habitat for 13 special status species, including sea turtles and migratory birds (Brown et al., 2011). Ecological adaptation in the Gulf of Mexico presents a unique challenge with climate change. The region is experiencing tropicalization, but the northern boundary at the Gulf states limits northward migration of species to cooler waters (NOAA Fisheries, 2019a), unlike the other coastal regions of the US.

Nearshore habitats in the Gulf of Mexico are susceptible to sea level rise, storm impacts, and anthropogenic activities affecting water quality and hydrology (Mendelssohn et al., 2017). Changes in salinity gradients, water quality, and freshwater supply are altering seagrass species distribution with unknown effects on habitat function (Ray et al., 2014). Salt marsh loss is occurring along the Gulf of Mexico coast, which will be exasperated by relative sea level rise, and effects on the biological productivity of important species are still unclear (Armitage et al., 2015; Smee et al., 2017). Science describing the effects of habitat change from both episodic and chronic stressors on productivity in the Gulf of Mexico will be critical for an EBM approach and for prioritizing management and mitigation objectives.

Specific research needs gleaned from our analysis of the survey and other information sources were:

- Ecological impacts of marsh habitat loss and restoration on spatial scales relevant to management (beyond the project-specific level)
- Combined effects of warming waters, deoxygenation, and coastal ocean acidification on the structure and productivity of food webs and cumulative effects on primary and secondary productivity
- Effects of shoreline change on the availability and accessibility of preferred habitat for fish, shellfish, birds, and wildlife
- Effects of changing sediment dynamics on barrier island habit and stability
- Responses of seagrass species composition and habitat value to sea level rise and changing salinity gradients

ES 12. Ecosystem connectivity pathways and processes

According to our sources, there are important science needs related to how ecological processes, which provide ecosystem services, and stressors move through the Gulf of Mexico ecosystem. Coastal and marine ecosystems that are distributed over a variety of habitats in the Gulf (including estuarine and shelf habitats) are intertwined to support a productive, resilient, and highly productive ecosystem. However, change driven by anthropogenic or natural forces can begin a cascade of effects for which our understanding is lacking. Research is needed to describe how these effects are transmitted and how they manifest themselves via indirect and nonlinear responses. While ecosystem-based understanding of the Gulf of Mexico has increased since the Deepwater Horizon oil spill, research is still needed to identify interconnections important to ecosystem function and to help predict ecosystem response to environmental change (National Research Council and Citation, 2014). Examples of these interconnections include the exchange of nutrients and biota between the nearshore and shelf and the role of freshwater inputs in productivity on shelf, pelagic, and benthic habitats. Science describing connectivity between estuaries and productivity in shelf waters is a priority for fisheries management (NOAA Fisheries, 2019a). Interactions between organisms and habitats within the water column (i.e., quantity and quality of pelagic habitat) are also poorly defined (NOAA Fisheries, 2019a). New analyses of ecological linkages and networks in the Gulf of Mexico are needed to move toward EBM (Gulf of Mexico Fishery Management Council, 2015).

> "Connectivity represents an ecological insurance policy."
>
> - Brown et al. 2011

A dominant feature in the region is the Mississippi River/Atchafalaya River Basin, draining greater than 40% of the contiguous US, providing freshwater, nutrients, and sediment to the northern Gulf of Mexico. A persistent hypoxic area develops each summer off west of the Mississippi River delta that varies in area depending on freshwater river inputs, weather conditions, and biological productivity (Rabalais and Turner, 2019). The 2008 Prospectus (NOAA National Centers for Coastal Ocean Science, 2008) recommended research to characterize hydrologic connectivity from watersheds to estuaries in order to support predictive models of habitat and biota responses to management actions. Survey responses describing locations throughout the Gulf of Mexico suggested there remains a need for research on the system-level ecological effects of variability in quantity and quality of freshwater supply. This need was also expressed in regional strategic planning documents (e.g., Gulf Coast Ecosystem Restoration Task Force 2011, Florida Sea Grant 2017). Freshwater inflows via 37 major rivers and groundwater carry organic matter, nutrients, and sediment (and pollutants) to support the productive tidal marshes and estuaries of the Gulf of Mexico (Mendelssohn et al., 2017). Regional restoration objectives discuss goals of returning freshwater flow to more natural patterns and reconnecting rivers to deltaic plains (e.g., Gulf Coast Ecosystem Restoration Task Force 2011, Joint Florida Gulf National Estuary Programs 2013). However, uncertainty surrounding how changes in freshwater quantity and quality will influence coastal ecosystems hinders decision-making. Ecosystem-based strategies in the Gulf of Mexico should consider ecosystem connectivity pathways and what processes are important to governing the energy flows along these pathways (Brown et al., 2011).

Within this category of ecosystem connectivity, the following examples could support EBM in the Gulf of Mexico region:

- Connection of nearshore to shelf habitats that allow for successful completion of complex life cycles
- Estuarine habitat dynamics and their ability to support associated biological productivity in response to variability freshwater quantity and quality
- Exchanges of nutrient and biota between pelagic and benthic habitats (e.g., influences of salinity, depth, and bottom types)

- Structure and energetic pathways of food webs along the dominant environmental gradients to support of biophysical modeling

ES 13. Ecosystem vulnerability to multiple ocean uses

Targeted research is needed to understand the cumulative effects of natural resource use on the health and stability of Gulf of Mexico ecosystems. Multiple-use pressures like fishing, coastal development, and energy exploration and extraction in the Gulf need to be managed in such a way that they promote both ecosystem and human community resilience. New science in this realm will help to support ecosystem modeling and identify ecosystem management tradeoffs (NOAA Fisheries, 2019a). The economic and social values of the Gulf of Mexico are part of what makes the region unique, but sustainably using these natural resources will be critical to the stability of the social-ecological system. The region's ports receive commercial goods and approximately 2/3 of the country's oil imports. Seventeen percent of domestic oil production (BOEM, 2017) and nearly half of the country's oil refining and natural gas processing capacity (US Energy Information Administration 2019) occur in the Gulf of Mexico region. Commercial and recreational fisheries and tourism are also important to the region's economy.

The following science examples illustrate critical research that could support EBM decision making:

- Impacts of energy exploration, development, and transportation on benthic habitats and wetlands
- Quantification of harvesting effects on key species that factor in changing environmental conditions and consider indirect effects that occur through food web interactions
- Physiological, behavioral, and health impacts of anthropogenic noise on marine species, particularly marine mammals

Socio-Ecological Science

Human communities in the region are intimately linked to the health and vitality of the Gulf's ecosystems. A better understanding of social and ecological linkages is an important need for informing decision-making in the Gulf of Mexico (Gulf of Mexico Alliance, 2016; National Academies of Science Engineering and Medicine, 2018). Science that promotes understanding of social and ecological connections in the region was among the most commonly expressed needs in surveys, interviews, and regional strategy documents. Socio-ecological research can help achieve the regional goal for a "stronger understanding of the connections between natural environments, ecosystem services, and human well-being" (Gulf of Mexico Alliance, 2016). One interviewed practitioner noted that EBM in the Gulf of Mexico is missing an understanding of how systems reverberate across one another and acknowledged a need to "stitch together" the issues in ecological and human environments.

Regional plans commonly expressed a need for predictive models to support decision-making for adaptation to climate change. One interviewed respondent described the key ingredient that could make a difference in EBM was ways to effectively bridge the connections between the ecological and human environments. They used the example of the Coastal Dynamics of Sea-Level Rise Model as a useful tool for understanding sea level rise impacts, but noted the need for such models to better integrate the human component.

SES 10. Effects of catastrophic events and methods to enhance management response

Multiple information sources called for research on human impacts, solutions, and risks related to extreme disturbances. They described a need for science that could help quantify the effects of episodic catastrophic events on ecosystems and human communities in the Gulf of Mexico and how they interact with ongoing chronic stressors on ecosystems (e.g., pollution, erosion) and human communities (e.g., relative sea level rise). Coastal communities in the region are susceptible to river flooding and water and wind damage related to tropical cyclones. Gulf states have seen major damage to infrastructure from tropical cyclones in the last 15 years, including the two costliest storms in US history (Katrina in 2005, and Harvey in 2017; National Hurricane Center 2018). Large-scale species-specific fish mortality occurred with red tide events in 2005, 2014, and 2018, and the Deepwater Horizon oil spill in 2010 affected a large geographic area of the Gulf. Ecological and human community impacts from these events raised questions about whether actions could be taken to better protect particularly high-quality habitats and charismatic species, such as dolphins. Sources also described a need for science to support predictive models of ecosystem response to catastrophic events.

Research to understand oil spill effects, response, and recovery was an important science need for the Gulf of Mexico region. Research is needed to better describe baseline socioeconomic characteristics of Gulf communities and ecosystems to better track impacts of events and to ensure effective communication of risk to the affected people (Hale et al., 2019). The Gulf Research Program, established as a result of the Deepwater Horizon oil spill, has an objective "To improve understanding of how social, economic, and environmental factors influence community vulnerability, recovery, and resilience" (National Research Council and Citation, 2014). This general sentiment was repeated in other regional plans and in our survey results.

Multiple sources discussed the need for tools to better prepare for and respond to catastrophic events. Science is needed to understand community networking capacity (Gulf Coast Ecosystem Restoration Task Force, 2011), as social networks may be an untapped resource in preparedness and response (Dambroski, 2018). For example, spillway releases to avoid flooding can affect ecological systems in the Gulf (e.g., prolonged periods of low salinity, algal blooms) and can shut down fisheries. Understanding how people cope with extreme events such as these could help inform EBM. Methods to engage these social networks and to capitalize on the deep cultural ties of Gulf communities could enhance recovery and resilience.

Research suggestions that could support EBM strategies and hazard planning included:

- Oil spill fate, effects, and recovery on habitats and organisms, including population responses of ecologically and commercially important species
- Human exposure and health effects of oil spills
- Cascading effects of large disturbances on understudied species (e.g., meso-pelagic organisms) and resulting effects on biogeochemistry (e.g., carbon sinking) and ecosystem dynamics on short and long time scales
- Opportunities and technologies to complement existing social networks to improve communication and community participation and enhance adaptation strategies during rebuilding planning after catastrophic events
- Predictive models to support hazard mitigation decisions and to identify opportunities to reduce harm and impacts and promote adaptive capacity

SES 11. Coastal community adaptation to sea level rise

Several elements of resilience, specifically regarding sea level rise, were expressed by survey participants, including natural buffers, hard engineering, institutional cooperation, and community vulnerability. In the Gulf of Mexico, solutions for human communities to adapt to sea level rise were paramount. The Gulf of Mexico is seeing the fastest rates of sea level rise in the US and the rise is expected to be even faster on the western Gulf coast. Greater than 4 million people live within the Gulf coast special flood hazard area (National Ocean Service and NOAA, 2011). Dealing with sea level rise (and land subsidence) in the region requires urgent innovation and action. Research is needed to understand the cost-effectiveness of risk reduction projects including nature-based approaches (Reguero et al., 2018) and innovative engineering and design (Coastal Protection and Restoration Authority of Louisiana, 2017).

Some specific suggestions for critical science related to human communities and sea level rise provided for the Gulf of Mexico were:

- Innovation for adapting existing infrastructure to rising seas that preserves or enhances both ecological and economic outcomes
- Socioeconomic vulnerability assessments of coastal communities to identify needs and opportunities to increase community resilience to sea level rise, tropicalization, and related effects
- Methods to coordinate agencies and stakeholders toward cooperative adaptation and resilience planning, including identifying knowledge barriers and implementation concerns that hinder adoption
- Social science to improve understanding of risk perception and environmental attitudes and behaviors

SES 12. Socioeconomic impacts of restoration and conservation actions

The theme of socioeconomic impacts of management actions was among the most frequently mentioned research themes needed to support EBM in several regions. However, in the Gulf of Mexico, particular emphasis was placed on the social and economic effects of restoration and conservation programs. Scientists and resource managers wanted to know: How does a restoration or conservation program affect the ecosystem, and in turn, local or regional human well-being? Future goals for restoration and conservation actions also figure prominently in regional planning and strategy documents (e.g., Joint Florida Gulf National Estuary Programs 2013, Coastal Protection and Restoration Authority of Louisiana 2017). It is hoped that research quantifying the socioeconomic benefits of these projects will help ensure effective and efficient actions are taken and that a formal evaluation of both ecological and social effects will garner support from stakeholders. However, existing social science research suggests that information alone may not be a sufficient incentive for many types of behavior change. Therefore, research is needed to identify what types of information, communication strategies, or pressures may be most useful for achieving goals and ensuring transparency across the full spectrum of impacts (ecological, economic, and social) of restoration and conservation actions.

Specific research to help describe the value of restoration and conservation actions in the Gulf of Mexico included:

- Case studies of socioeconomic consequences of sea level rise and other climate change effects (without action) and benefits of restored environments (value of prevention)
- Identify and quantify specific links between aquatic health and economic health
- Improve information on the socio-demographics of Gulf users, such as tourism and recreational anglers
- Cost-benefit analyses of potential restoration scenarios, including the sustainability of materials transfer among regions (rock and sand), and with consideration of the local conditions (e.g., erosion rates, hydrodynamics)
- Understanding the link between built and natural environments (e.g., shoreline modification, migration corridors) and the cost-effectiveness of nature-based approaches for achieving multiple ecological restoration goals
- Habitat value of artificial structures built for mitigation (e.g., artificial reefs as habitat replacement, living shorelines)
- Socio-ecological benefits and costs associated with reconnecting rivers to deltaic plains

Governance and Incentives

Survey participants acknowledged a need to better translate science for management and make recommendations that can garner the support of decision makers. It is possible that this sentiment was behind much of the science suggested in surveys and interviews. For example, the two most popular themes for critical science needs in the Gulf were socioeconomic impacts of management actions and use conflicts and tradeoffs (Figure 33). Governance and political will were described as a hinderance to implementing EBM by 72% of survey respondents (Figure 31). Existing institutional structure was a major theme in survey responses describing non-science barriers to EBM (Figure 32). Considered together, these results present a need for strategies to understand constraints of the current institutional structure and approaches that may be effective in achieving consensus on actions to promote the adoption of EBM in the Gulf of Mexico region.

GI 9. Strategies to support systems-level perspectives in fisheries management

Ecosystem-based fisheries management (EBFM) was mentioned repeatedly by respondents to our survey and other reference sources and is a path forward to achieving EBM. Regional priority documents and survey responses suggested a need to better understand the role of habitat and greater ecosystem processes to predict potential influences of change on fisheries (e.g., climate change effects on species movement) and to avoid unintended interactions (e.g., bycatch, disruption of trophic structures) to support EBFM. Fisheries in the Gulf of Mexico have begun to recover from historical overfishing mostly due to harvest limits put in place over the last 20 years, but other ecosystem stressors and changes in ecosystem productivity are likely confounding a more rapid and complete recovery (Karnauskas et al., 2019). Climate change presents a further challenge for fisheries management and Gulf of Mexico communities are likely to be especially affected (Pershing et al., 2018). The supporting science will need to help account for the effects of ocean warming, acidification, and deoxygenation (Karnauskas et al., 2015). Potential changes in habitat and species distributions in response to climate change are highly uncertain. Fisheries management will need to develop strategies that account for the multiple ways the Gulf of Mexico ecosystem will change in the future in order to ensure effective management advice and decisions and continued recovery and long-term sustainability of the fisheries (Karnauskas et al., 2019).

> "Resolving natural resource conflict in Barataria with science that could answer fishers' questions about business planning for the next 3-10 years would provide a template for any other problem you will have in the Gulf."
>
> -Responding scientist

Research is also needed to better understand the human dimensions of fisheries in the Gulf of Mexico. Social science for fisheries was expressed as a priority throughout the region (e.g., Lovett et al. 2016, Florida Sea Grant 2017, Louisiana Sea Grant 2019). Development of social and economic indicators and characterization of the human dimensions of fishing communities could support and advance EBFM (Gulf of Mexico Fishery Management Council 2015). EBFM, and thus EBM, must be able to quantify and predict the social and economic effects of fisheries management actions (NOAA Fisheries, 2019a). Survey responses and informal discussions with fisheries scientists and managers in the region supported the notion that better social and economic science in the Gulf of Mexico is a critical need.

High priority science needs included:

- Development of social and economic indicators of fishing communities and a cohesive data management system to encourage data sharing and consistency
- Summertime hypoxia and harmful algal bloom effects on key variables used to inform management, such as how hypoxia affects the representativeness of fisher behavior and therefore fishing efficiency
- Habitat associations causing overlap among target and bycatch species, and effects of interannual variation in environmental conditions (short-term and medium-term) and climate change (long-term) on harvest opportunities
- Models to enable dynamic coupling of socioeconomic effects with ecological and fisheries dynamics to evaluate alternative management strategies

GI 10. Ecological resilience links to human community well-being

A common theme in regional plans for the Gulf of Mexico was to better understand the anticipated effects of climate change on marine ecosystems and the human communities that depend on them (e.g., Lovett et al. 2016, Louisiana Sea Grant 2018, NOAA Fisheries 2019). Planners in the Gulf of Mexico would benefit from a better understanding of the current status of ecosystems in terms of their resilience to the effects of climate change and the ecosystem services they provide. This science could be used to support economic analyses and identify incentives for natural and green infrastructure (NOAA, 2015). Given the many interests at stake in the region, effective institutional actions are needed to identify and manage risks.

> "We should be thinking of nature and all of nature's systems as a form of infrastructure."
>
> -Sarah Murdock, The Nature Conservancy (EESI, 2019)

The following are examples of research to support and communicate the links between ecological and human community resilience:

- Case studies of coastal development projects that evaluate their ability to provide both ecological and human community resilience
- Ecosystem response to stressors to assess potential long-term ecosystem resilience and prioritize among alternative conservation/restoration actions
- Designing effective participatory processes to engage communities in resilience planning and prioritization that allows transparent evaluation of tradeoffs
- Reducing technical and implementation barriers by creating incentives for projects that enhance ecosystem resilience to environmental change and multiple anthropogenic stressors
- Ecological effects of shoreline projects (hardening, riprap, breakwaters) and the potential for improving existing structures, or developing new structures, that preserve ecosystem value and function (e.g., nature-based design) while offering human community protection from erosion

CONCLUSION

The most commonly described science needs for EBM in survey responses and follow-up interviews in the Gulf of Mexico were related to improving understanding of the effects of management actions on changing social and ecological systems. Sources described a need for new methods and tools to more efficiently consider the interacting effects and tradeoffs related to coastal management decision making. The 2008 Prospectus identified a need in the Gulf of Mexico for coupled modeling to better understand and predict pollutant transport and ecosystem and fisheries responses to multiple interacting stressors. Our analysis suggested a widening of priorities to describe ecosystem connectivity pathways and habitat change. Sources also identified a need for science to help develop integrated models and tools to evaluate tradeoffs and cause and effect of management actions. These tools may be useful to support regional needs for improved collaboration and cooperation toward EBM, which was considered by several respondents as a particular challenge because of conflicting interests. Another common concern expressed by survey respondents and re-counted throughout regional planning and strategy documents was ecosystem and human community resilience in the face of catastrophic events (e.g., hurricanes and oil spills) and climate change (especially sea level rise). Survey and interview respondents and other sources in the region indicated a broadening of priorities and science objectives to support an EBM approach. The science described herein was identified to serve to enhance EBM strategies and success in the Gulf of Mexico.

Critical and Emerging Science to Support Ecosystem-Based Management

West Coast

Ecosystem Science
- Interactions at the land–sea interface
- Analyses of coupled biophysical processes and habitat integrity
- Impacts of climate change on habitats and ecosystem function
- Ecosystem impacts from in-water anthropogenic activities

Socio-Ecological Science
- Tradeoff analyses to support prioritization and decision making
- Innovative solutions to design and achieve sustainability and resiliency goals
- Strategies to enhance inclusive coastal planning, equity, and environmental justice

Governance and Incentives
- Strategies to achieve greater sustainability of fisheries and aquaculture
- Management interventions for sensitive and endangered species

West Coast

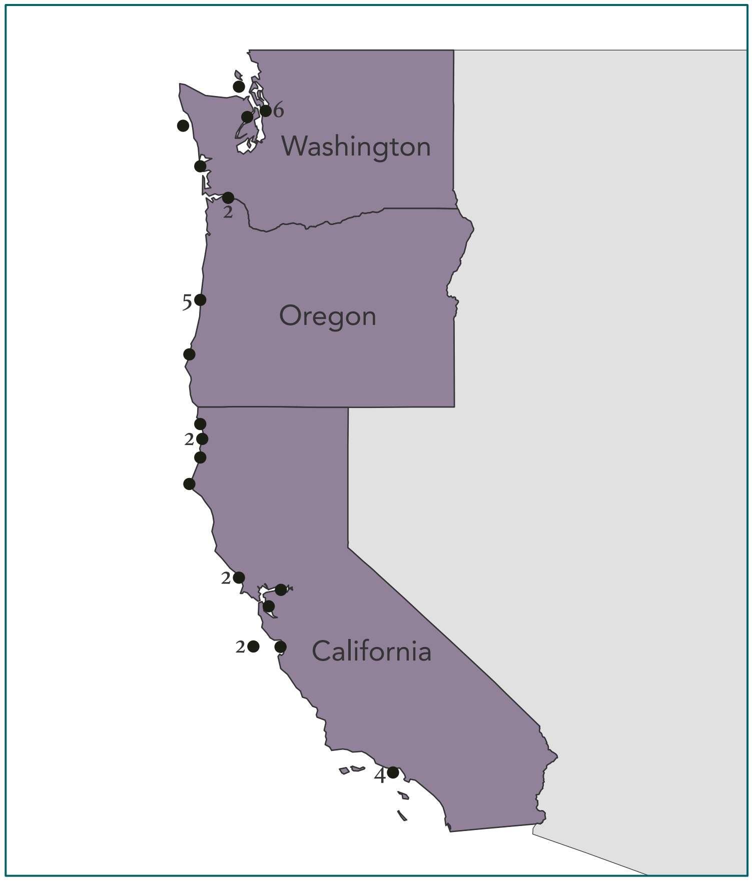


Figure 34. West Coast region and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The US West Coast region described herein includes the nearshore and state waters of California, Oregon, and Washington. A major feature of the West Coast region is the California Current, and eastern boundary current that circulates cool, nutrient-rich water from north of the U.S. border along the coastlines of Washington and Oregon and southward to Baja, California. The southern Salish Sea, including Puget Sound and the Strait of Juan de Fuca, is a particularly productive and unique ecosystem of the Pacific Northwest. Other coastal habitats range from rocky shorelines to sandy beaches.

Features of EBM on the West Coast

Ecosystem-based management on the West Coast has been implemented to some degree at the local level for more than a decade (e.g., Humboldt Bay Initiative, Port Orford Ocean Research Team, Puget Sound Partnership) but full consideration of the interconnected ecosystems of the West Coast also required application at the regional scale (Lester et al., 2010). To this goal, the West Coast EBM Network was a helpful forum for sharing ideas and progress in some of the early marine EBM initiatives in the region (Wondolleck and Yaffee, 2012). Regional cooperation for ocean management and planning on the West Coast has gone through several organizational phases over the past decades (e.g., West Coast Governor's Alliance on Ocean Health, West Coast Regional Planning Body, the West Coast Ocean Partnership). The West Coast Ocean Alliance is the current incarnation of a regional partnership working to coordinate governments and tribes directly toward holistic management strategies such as EBM (westcoastoceanalliance.org). California's network of marine protected areas is a key partnership of government agencies, tribes, and other coastal resource users that facilitates an EBM approach (California Department of Fish and Wildlife, 2016). NOAA's Integrated Ecosystem Assessment (IEA) program promotes the EBM framework with efforts to summarize the status of regional ecosystems and evaluate risks and management approaches to inform decision making (Levin et al., 2013). Annual reports for the California Current Ecosystem are prepared by the IEA program and used to support the ecosystem perspective in regional fisheries management plans (Harvey et al., 2020; Pacific Fishery Management Council, 2020).

Perceptions of EBM on the West Coast

We conducted a national online survey (Appendix B) to elicit perceptions of coastal EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. We discuss the West Coast region within a single chapter with the recognition that there are major differences in many aspects among the systems and issues relevant to the California coast and those of Oregon and Washington, including river-dominated versus smaller estuaries, and well-studied systems versus data-limited systems. While these differences will affect the design and implementation of EBM (as it is a place-based strategy), ecosystem connectivity along salinity gradients and the estuary-nearshore-ocean continuum are major themes in many locations of the West Coast. In addition, broad areas of the West Coast are largely managed as single regions (e.g., Pacific Fishery Management Council, California Current Large Marine Ecosystem) (NOAA NW/SW Fisheries Science Centers, 2016; NOAA Fisheries, 2019h; Pacific Fishery Management Council, 2020) with partnerships and states working at the sub-region or local level. Many similar science needs were identified from our survey and review of the planning documents when the needs are viewed from a general (high level) perspective.

For the West Coast region, we received 34 survey responses and conducted follow-up interviews with three or these participants. Survey respondents self-identified their roles (Table 5A) and we identified organizational affiliations from the email addresses provided in survey responses (Table 5B). Thirty-one respondents agreed that EBM was a goal in their work, with 26 saying it was currently being used. Five responded that, while EBM was a goal in their work it is not currently being used.

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. Two respondents described two separate locations, thus the results and discussion that follow describe perspectives of EBM for 36 locations.

Table 5. Self-identified work titles (A) for West Coast respondents and organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	16
Scientist & Resource manager	1
Resource Manager & Policy maker	4
Resource manager only	5
Policy maker only	2
Scientist & Policy maker	1
No response	5
Total	**34**

B.

Organization	
Federal government	6
State government	5
Non-governmental organization	4
Tribe	1
University	4
Unidentified	14
Total	**34**

The general priorities and views of respondents on the West Coast were similar to those that emerged in other regions. In the 36 locations on the West Coast named in the survey results, 36% of survey respondents agreed that EBM was successfully being implemented, while 53% disagreed (Figure 35). The majority of respondents indicated that there were important science and communication needs that, if fulfilled, would enhance the likelihood of successful implementation of EBM in West Coast locations (Figure 35). Responses were generally similar (75% to 83% agree) for the remaining questions about what research and advances are needed to enable full implementation of EBM: more scientific understanding, additional social research, extended monitoring, clarity in goals and plans, and meaningful stakeholder interactions.

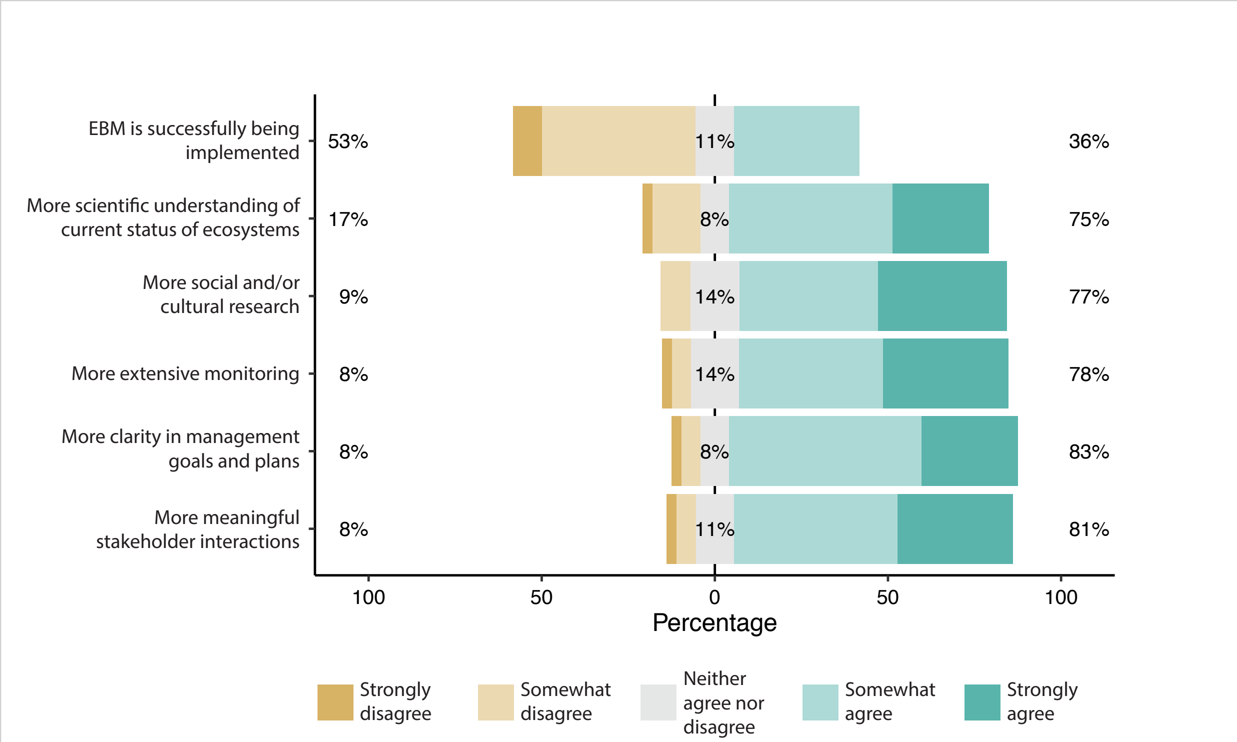


Figure 35. Practitioner opinions on needs before fully implementing EBM in locations in the West Coastal region (SQ12, n=36). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad issues in the West Coast region, *water quality*, *habitat integrity*, and *coastal resilience* were most commonly rated as very or extremely important issues (Figure 36). Water allocation, human health, and invasive species were also listed multiple times as extremely or very important. In the 17 write-in responses listing additional issues that were deemed very or extremely important for their location, one or both of two broad issues were captured in 65% of follow up comments: climate change was referenced in 10 of the 17 comments (sea level rise specifically identified seven times), and fisheries issues were mentioned in seven of 17 comments. We expected to see the subject of fisheries in these responses as EBFM is an existing effort in the region. We did not explicitly list fisheries in this survey query to encourage other less prevalent issues. We also intentionally omitted climate change from the list under the rationale that its effects would be captured within the listed issues. Results of our analysis for several regions, including the West Coast, suggested that these topics were regarded by many respondents as distinct environmental concerns within EBM.

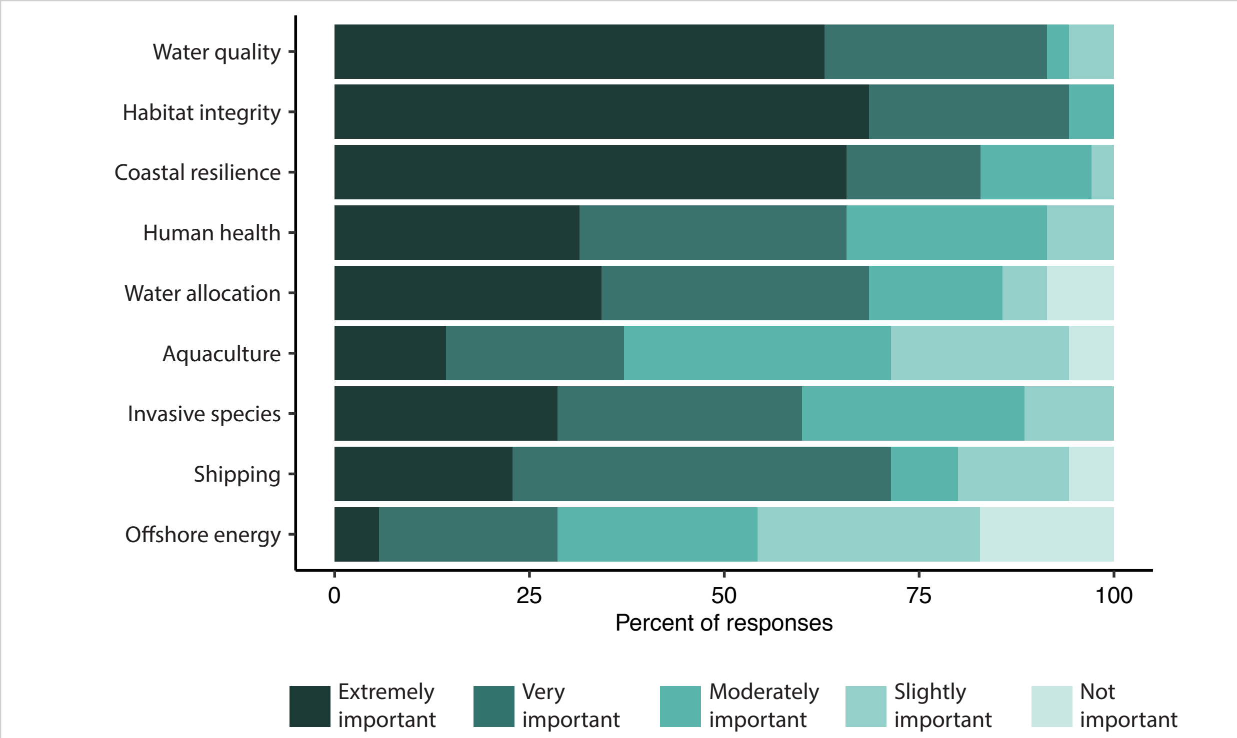


Figure 36. Priority issues as described by online survey respondents (SQ7, n=35).

Surveys and follow-up interviews of West Coast respondents suggested collaboration and cooperation toward EBM in the West Coast have been particularly challenging. We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). *Developing actionable goals* was commonly perceived among the most difficult elements of EBM, with 69% of respondents ranking it as the most or second-most difficult (Figure 37). Nearly half of participants ranked *implementing an interdisciplinary approach* as the most difficult aspect of EBM to achieve (Figure 37). Both of these challenges were articulated by an interviewed scientist who noted two major needs for EBM: better communication of forecasting for potential management actions and a "forum for interdisciplinary dialog and interaction." Another interviewed scientist noted that agencies are still targeting projects toward single-species issues, thus hindering understanding and consensus-building around the value of the ecosystem.

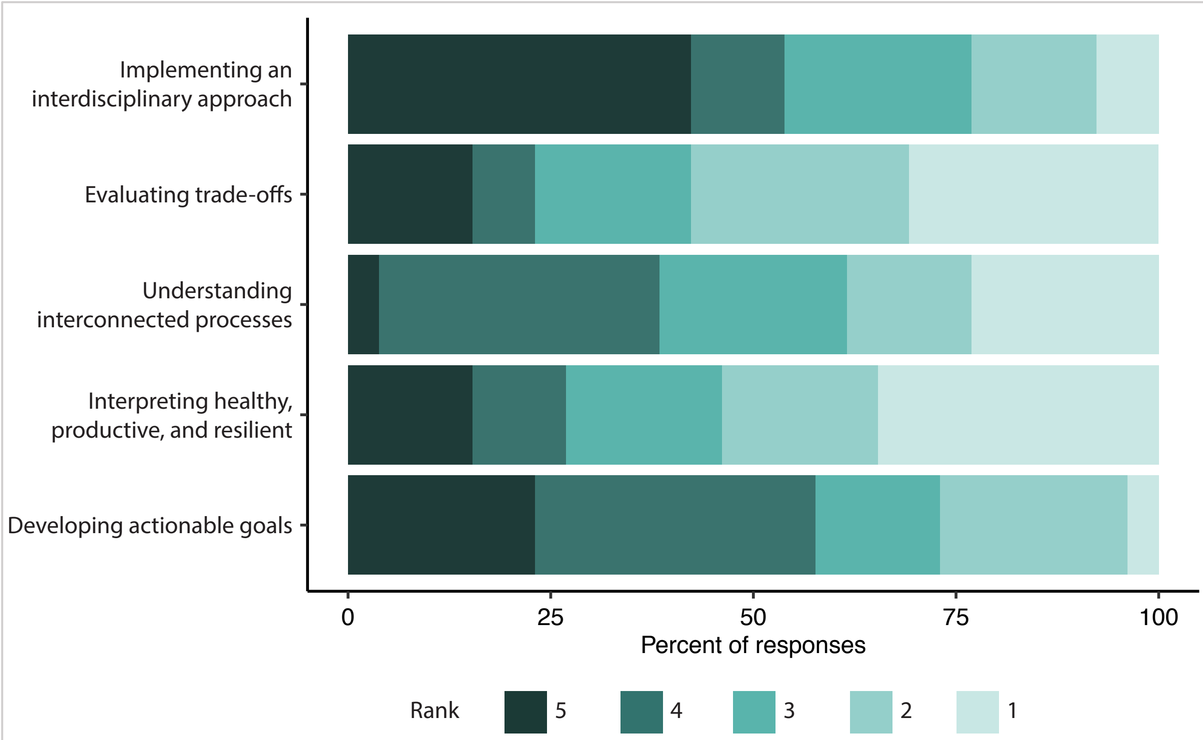


Figure 37. Perceived relative difficulty of EBM attributes where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=26).

While the majority of survey respondents agreed that more science is needed before fully achieving EBM (Figure 35), greater than 50% of the respondents considered monitoring, data availability, and understanding of ecological linkages as sufficient to currently support EBM planning and implementation (Figure 38). Institutional capacity, stakeholder dynamics, and interagency communication were roughly split between hinders versus supports. Governance and political will (54% hinders), and especially resource availability (71% hinders), were most commonly described as hindering EBM (Figure 38).

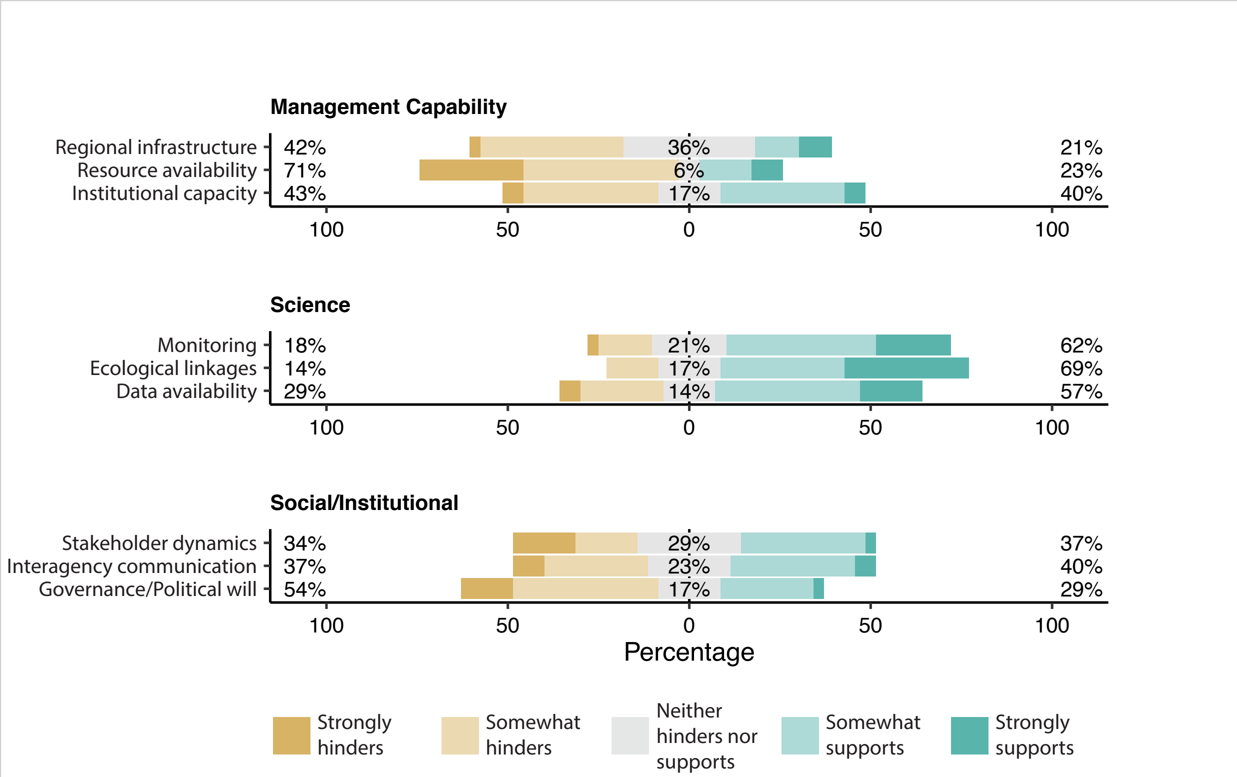


Figure 38. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents on the West Coast (SQ11, n=35).

Responses to the question, *what is the biggest non-science barrier to EBM?* most commonly referred to concerns related to the cooperative aspects of governance. The top three themes appearing in the 28 write-in responses were: political will (9), coordination among agencies (7), and stakeholder buy-in (7) (Figure 39). There was a slight, but notable, difference in the distribution of these issues between responses describing Pacific Northwest locations and those in California.

Five of 15 comments from California participants described non-science barriers to EBM related to coordination across boundaries, followed by comments related to political will and resource commitment (each mentioned 4 times). An interviewed scientist describing EBM in Southern California expressed a need for people that understand political strategy and a forum for effective interdisciplinary dialog and interaction. Several sources in California acknowledged that successful EBM is occurring where the management responsibility is most clearly defined and where consistent collaboration among stakeholders and agencies occurs (e.g., the National Estuary Research Reserve system, Marine Protected Areas).

Non-science barriers listed by respondents working in Pacific Northwest locations most commonly included issues of political will and stakeholder buy-in (noted by five and four participants, respectively). Survey responses within these common themes described challenges of coordinating priorities for management among the many stakeholder groups that exist at an ecosystem scale. An interviewed scientist and policy maker working in Puget Sound further described the difficulty of working through tradeoffs related to ecosystem restoration and land-use (farmland), using the adage that perfection has been the enemy of the good.

Figure 39. Coded themes of responses discussing non-science barriers to EBM (SQ42, n=28) in the West Coast region. The size of words is relative to the frequency of the code.

Our survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. The most common responses in the West Coast region were related to understanding and anticipating future impacts of climate change (nine of 30 responses, Figure 40). After climate change, the major themes of named critical science needs varied somewhat with the discernable differences in biophysical characteristics between locations in Oregon and Washington and the California coast. While the California Current shapes the intricately interconnected West Coast, some ecosystem concerns of the temperate Pacific Northwest may be substantially different from those of the semi-arid southern California coast. In the 15 responses describing the locations of the Pacific Northwest, issues related to food web, species distribution and productivity (but not specifically fisheries), and methods to achieve EBM each appeared in three responses. In the 15 responses describing the California coast, after climate change, habitat mapping and physical oceanography research were the most common science suggestions (each included three responses).

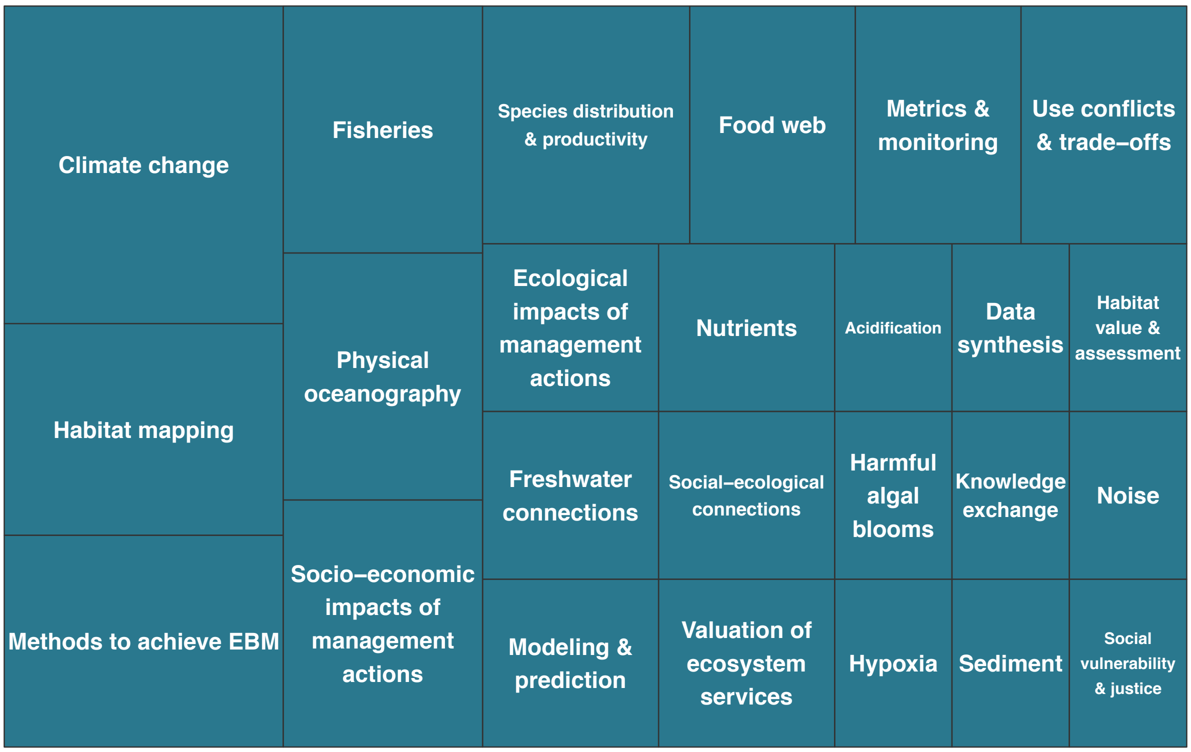


Figure 40. Topics appearing more than once in survey responses describing critical science needs for EBM on the West Coast (SQ10, n=30). Larger boxes correspond to more frequent mentions.

Critical and Emerging Science to Support EBM in the West Coast Region

One of the purposes of this project was to provide an update to the Regional Ecosystem Research Prospectus (2008 Prospectus), a document that has helped guide regional coastal science research to address EBM and other management needs (NOAA National Centers for Coastal Ocean Science 2008). Broad research priorities presented in the 2008 Prospectus for California included characterization of species abundance and distribution with ocean change, and methods to balance socioeconomic and ecosystem priorities. The research needs highlighted in the 2008 Prospectus for Washington and Oregon included the identification of anthropogenic and climate stressors and their impacts on coastal habitats and water quality, with an emphasis on application to fisheries sustainability and aquaculture. Both areas included needs for science to describe the pollutant source and transport, improve understanding of impacts and prediction capacity of harmful algal blooms, and the extent, spread, and food web alteration of invasive species.

Ecosystem Science

Overfishing and environmental impacts of coastal development have contributed to degradation of West Coast ecosystems. Increases in shipping traffic, offshore energy development, and aquaculture are influencing the stability of the marine environment. The effects of climate change on the West Coast, such as sea level rise, increasing water temperatures, and ocean acidification, are contributing to uncertainty for critical habitats, important species, and human well-being (Gonzalez et al., 2018; May et al., 2018). Survey and interview participants noted the need for ecosystem science to help develop tools to evaluate and prioritize restoration and resilience objectives on the West Coast. Planning and strategy documents throughout the region prioritized mapping and quantification of habitats and the development of integrated biogeochemical models to understand and predict ecosystem change and focus management strategies (e.g., Smith River Rancheria 2015, Washington State Department of Ecology 2017, Puget Sound Partnership 2018).

An example of the broad ecosystem science needs and application to EBM was provided by an interviewed scientist working in Southern California. They noted that wetlands have not been sufficiently assessed for their habitat value or resilience potential while at the same time they are particularly compromised by sea level rise and coastal development. The scientist argued that gaps in systems-level understanding such as this can lead to misdirection of financial resources by placing restoration efforts in areas with low potential for provision of long-term ecosystem services, rather than in locations that would provide the most benefit. Our sources suggested a variety of new ecosystem science in the region, often with a focus on how this knowledge would benefit prioritization and decision making for conservation or restoration investments and management activities.

ES 14. Interactions at the land-sea interface

Among the most common science suggestions in survey and interview responses on the West Coast was greater characterization and quantification of the effects of anthropogenic disturbances in watersheds and potential methods to mitigate their impacts on coastal ecosystems. Respondents noted a need for science to better describe relationships between watershed use and condition (including freshwater supply) and nearshore water quality and habitats. For example, sources acknowledged a need for research to better quantify the cumulative impacts of agricultural practices on trophic relationships and the effectiveness of conservation and restoration actions. Regional strategy documents also commonly regarded the need for increased research on the impacts of contaminants (e.g., pharmaceuticals, pesticides, plastics) and potential regulatory or behavior change strategies for mitigation (California Ocean Protection Council, 2019). Respondents and regional planning documents expressed a need for better characterization of ecosystem interactions and the influences of management actions in the watershed (e.g., Washington State Department of Ecology, 2017; Puget Sound Partnership, 2018).

The following science was suggested to improve understanding of the interconnections between land use and nearshore resources:

- Ecosystem and habitat effects of pollutants in estuarine and nearshore waters from loadings originating in the watershed (e.g., plastics, nutrients)
- Potential engineering methods to preserve and restore shoreline function for multiple objectives, such as for critical habitat, sediment stabilization, and pollutant capture and cycling (i.e., wetland and estuarine habitats and associated ecosystem services)
- Sediment budgets within estuaries to address water clarity issues, especially in estuaries with large river inputs, to provide a baseline for assessing the impacts of activities associated with sand mining, erosion, and shoreline stabilization
- Methods for predicting bioaccumulation and mix of toxins in fish from riverine and local discharge sources, such as harmful algal blooms, agriculture, sewage, urban runoff, and industrial activities

ES 15. Analyses of coupled biophysical processes and habitat integrity

The 2008 Prospectus described needs for research to understand changes in species distributions and food web alterations, with a specific emphasis on advancing modeling capabilities. Our analysis suggested these are still important research needs to improve the implementation of EBM strategies. Surveys and interviews suggested a need for tools and methods to improve systems-level understanding in the region. Other sources highlighted a need to improve understanding of trophic energy flow and ecological interactions (e.g., Northwest Indian Fisheries Commission, 2016; Pacific Fishery Management Council, 2020), needs that also appeared in survey responses, particularly in those describing needs in the Pacific Northwest.

Multi-disciplinary biophysical science on the West Coast is needed to support conservation and management of species and ecological relationships. Areas of the West Coast have a wealth of data that several sources suggested could be exploited to support EBM. Further efforts toward data and information synthesis at the system and regional scales could unify the high volume of historical data, and capture the ever-increasing generation of new data, to support status and trend analyses and improve physical and ecological models and their coupling.

The following research would help fulfill critical needs for ecosystem modeling:

- Development of data, mapping, and modeling tools to link climate indicators of broad-scale inter-annual variation and decadal-scale regimes to localized coastal physics, water quality, and food web dynamics
- Field data collection and modeling techniques for assessing wetland integrity and evaluating capacity for preservation/restoration of critical habitat
- Connectivity of habitats for organisms with complex life cycles or with migratory pathways that cross salinity gradients
- Monitoring and modeling to improve understanding of nearshore chemistry and physics and dependence on local and regional ocean circulation patterns

ES 16. Impacts of climate change on habitats and ecosystem function

Climate change was the most prevalent concern expressed in sources throughout our analysis. Survey responses and regional reports for the West Coast described a need for new ecosystem science to better understand recent and anticipated changes in coastal ecosystems influenced by climate change. Ocean acidification and hypoxia were prominent examples of stressors that are disproportionately affecting near-shore areas of the US West Coast, with implications on ecosystems that call for rapid adaptive management to safeguard the socioeconomic stability of the coastal zone (Gruber et al., 2012; Chan et al., 2016, 2017). Several respondents expressed concerns that decision making for resource management will become increasingly complicated with climate change and managers in the region do not have strong processes in place to successfully adapt for resiliency.

Science suggestions to help anticipate and respond to the challenges of climate change on West Coast ecosystems included:

- Development of multi-stressor data analysis and modeling approaches capable of linking laboratory results to field conditions to understand the effects of ocean acidification, warming, and hypoxia on habitats, species, and food webs

- Characterization of the impacts of decadal and climate changes in the marine food web on movements, feeding, growth, and reproduction of marine mammals
- Projection of climate change effects on variability of salinity, temperature, nutrients, and water clarity along the river-estuary-nearshore continuum on seasonal (monthly) time scales
- Quantification of climate change effects on precipitation patterns and changes in key environmental and water quality variables
- Climate change effects on extreme years, such as drought, and how the effects cascade through the physics, biogeochemistry, lower food web, and into the upper trophic levels.
- Habitat use and dependency of anadromous fish and the effects of water quality changes within the riverine, estuarine, nearshore, and pelagic environments on successful migration

ES 17. Ecosystem impacts from in-water anthropogenic activities

Sources describing critical science needs on the West Coast commonly acknowledged the multitude of anthropogenic activities that contribute to the region's economic and cultural richness and the importance of managing for sustainability. Research is needed to improve understanding of the broad ecosystem impacts of these activities and identify mitigation strategies that preserve ecological and human well-being. Survey comments noted a need for monitoring programs that are capable of providing timely and appropriate data that can contribute to decision tools and be accessible to resource managers.

The following are examples of critical science needs related to anthropogenic activities that appeared through our analysis of the West Coast:

- Effects of anthropogenic marine noise on marine mammal behaviors
- Development of integrated biogeochemical models to project species and lower ecosystem responses to changing water routing and management strategies
- Interactions among commercial fisheries and non-commercial species (e.g., bycatch, food web alterations) and potential amplification due to climate change

- Quantification of ecological interactions (including cumulative effects) of aquaculture activities on the local nearshore environment
- Development of cost-effective methods for high-resolution and/or dynamic habitat mapping to improve spatial planning for potential ocean uses such as offshore wind, shipping, and fishing

Socio-Ecological Science

To fulfill the Puget Sound Partnership's needs for ecosystem recovery strategies to be better informed by social science, Breslow et al. (2019) identified high priority social science needs for the region. Their evaluation recognized many important socio-ecological research questions but converged on a top priority to understand climate change impacts on holistic health and well-being of communities in the region, which was also a common concern expressed by respondents to our survey. Similar to other findings of the Breslow et al. analysis, we determined the need for new knowledge to understand food web changes and associated impacts on human well-being, social and ecological impacts of coastal zone development, and improved integration of diverse values and traditional ecological knowledge into management. The research needs that were described in regional strategy documents also included a broad range of topics related to socio-ecological science. Multiple sources expressed a need for decision support tools that integrate natural and social science information (including ways to identify and measure social and cultural values) to advance EBM (e.g., Harvey et al., 2016; Puget Sound Partnership, 2016; California Sea Grant, 2018).

SES 13. Tradeoff analyses to support prioritization and decision making

The quantification of ecological and social effects of management actions was a commonly described need to support EBM in West Coast surveys, interviews, and plans. Regional planning documents along the West Coast set priorities to examine the ecological and socioeconomic aspects of coastal development and find methods to minimize the negative impacts (e.g., California Sea Grant 2018, Oregon Sea Grant 2021). A surveyed scientist working in the Pacific Northwest named quantitative tradeoff analyses as "the most critical [need] for conveying relative importance of actions to policy makers." Another interviewed scientist and policy maker working in the Puget Sound described a need for science to characterize the economic and social impacts of potential management actions as important for gaining support for policy decisions. They provided an example where a well-informed tradeoff analysis could help decision makers faced with the challenge of weighing the need for restoration of historical estuarine habitats, in part to achieve salmon recovery targets, against the surrender of farmland that would be necessary for such restoration.

Examples of new knowledge that would understanding of tradeoffs in West Coast ecosystems included:

- Methods to enable retrospective comparison of ecological and social impacts and tradeoffs among historical and ongoing conservation and restoration programs
- Quantification of the cumulative ecological and social effects that simultaneously deal with both management and restoration actions
- Cost-benefit analyses of potential development scenarios (and associated envisioned futures under climate change) and their effects on agriculture (food security) and other ecosystem services

SES 14. Innovative solutions to design and achieve sustainability and resiliency goals

An interviewed scientist and policy maker working in the Puget Sound region suggested that social-ecological systems thinking will be an important strategy for EBM to facilitate the "hard conversations about moving infrastructure" and adapting to climate change. They noted that the holistic paradigm is not as broadly accepted as it needs to be, but recent collaborations have been encouraging. Creative approaches to managing for sustainability and resiliency that provide multiple benefits will be critical to overcoming EBM implementation challenges. A common priority appearing in regional planning documents (e.g., California Ocean Protection Council, 2012; NOAA Fisheries, 2019) was more efficient alternatives to restoration and conservation of ecosystem services that would require investment in new technologies and pilot projects. The improved understanding of ecosystem responses to climate change described previously will be most applicable alongside sociological and economic research that can identify barriers to, and opportunities for, stakeholder and political support for action.

Our analysis recognized socio-ecological science needs for the West Coast to identify:

- Communication approaches and economic incentives to encourage sustainable behaviors and decision making for coastal communities and ecosystems
- Development opportunities (e.g., land-use planning) that simultaneously address economic goals while also reducing hazard vulnerability and increasing environmental equity and community wellbeing
- Opportunities for development of marine renewable energy (e.g., tidal, wind, thermal) that complement (minimizes conflicts) with other uses of the same environment

SES 15. Strategies to enhance inclusive coastal planning, equity, and environmental justice

Several survey respondents and regional strategy documents and plans called for science that could improve the understanding and integration of social and cultural values in coastal management (e.g., Oregon Sea Grant 2018, Puget Sound Partnership 2018, Washington Sea Grant 2018). The challenges of habitat and species displacement and loss influenced by anthropogenic land and water use and climate change have unique impacts on traditional and cultural practices and livelihoods. Tribes throughout the West Coast region have developed climate change assessment programs and adaptation plans and have prioritized the establishment of partnerships between Tribal and non-tribal scientists to work toward solutions to the impacts of climate change (Dalton et al. 2016, Northwest Indian Fisheries Commission 2016). But broader socio-ecological research is still needed to assess coastal community resilience (University of Southern California Sea Grant, 2017; Washington Sea Grant, 2018). Identifying and monitoring appropriate indicators of human community health and well-being is critical to resource management and communication within and across borders (Donatuto et al., 2014; NOAA Fisheries, 2019h).

Suggestions for social science research to enhance environmental equity and EBM implementation included:

- Identification of social and economic characteristics of coastal communities, including cultural practices and perspectives on preserving cultural resources and maritime heritage

- Assessment of the projected effects of coastal development and climate change on cultural resources, including influences on resource-based livelihoods and local communities
- Methods for collaborative development of conservation and restoration strategies that include Indigenous knowledge holders, ecosystem scientists, resource managers, and policy makers
- Integrated socio-ecological analyses to incorporate social equity and sustainability in coastal development planning

Governance and Incentives

It was suggested a decade ago that a lack of science on the US West Coast was not the barrier to EBM progress (Lester et al., 2010; Wasson et al., 2015), and a survey respondent expressed this when asked to describe critical science needs. They wrote, "Scientific information is not a limiting factor; political will and financial support are." The Puget Sound Partnership (2018) similarly emphasized the hindering of recovery efforts by a lack of "broad and sufficient political will to meet true investment needs." While ecological and social research needs exist to broaden the scope of EBM, as discussed, our analysis agreed that methods to address governance and institutional barriers are needed to enhance the implementation of EBM in the West Coast region. Further, multiple sources working in the region also suggested a need for improved accessibility and use of that science in order to achieve regional management objectives. For example, the California Ocean Protection Council noted a specific need for strategies to enhance institutional capacity for connecting science to management (California Ocean Protection Council, 2012). The 2008 Prospectus similarly emphasized a need for better connection of the needs of managers in California with the expertise of marine scientists, suggesting this gap in communication has been an enduring issue in the region.

GI 11. Strategies to achieve greater sustainability of fisheries and aquaculture

Objectives for fisheries management in the region include implementing an adaptive approach that can respond to the evolving understanding of the region's fisheries and promotes the well-being of the entire ecosystem (Pacific Fishery Management Council, 2020). Targeted research (ecological and socioeconomic), indicator development, and cooperative and adaptive fisheries management techniques are needed for EBM, and management in general, to be able to effectively adapt to climate change (California Department of Fish and Wildlife, 2018). Goals for sustainability of fisheries and aquaculture on the West Coast can be met in part with research that characterizes the ecological and social connections within the ecosystems. However, sources also called for the characterization of strategies that promote sustainable fisheries management, such as case studies of successful consensus building for fisheries policy or evaluation of the effectiveness of marine protected areas.

Illustrative examples of the science needs for West Coast fisheries and aquaculture were:

- Techniques for fisheries management to adapt to changing species distributions and ranges while maintaining some continuity with historical and present-day management actions
- Case studies and examples of management strategies that promote sustainable fisheries and aquaculture
- Methods to include multiple species and new knowledge about changing natural climate factors (e.g., circulation, upwelling) and variation in regional and local environmental drivers (e.g., temperature, salinity, prey base) into fisheries stock assessments and the resulting management advice
- Design and operational strategies and technologies to improve economic viability of aquaculture
- Habitat characterization and species research to evaluate potential for alternative species and locations for aquaculture, particularly under ocean acidification or other changes

GI 12. Management interventions for sensitive and endangered species

Methods and technologies to improve protection and recovery strategies for threatened and endangered species of the US West Coast were prioritized in the region's management and science plans (e.g., Washington State Department of Ecology 2017, Puget Sound Partnership 2018). The California Current ocean ecosystem is home to approximately 30 threatened and endangered species vulnerable to habitat loss, stressors related to climate change and pollutants, and mortality as incidental catch (Oceana, 2020). Our analysis highlighted a need for innovative high-level management interventions, such as incorporating incentives to encourage protective practices and technologies to reduce anthropogenic interactions with threatened species.

The following cross-cutting research could enhance EBM effectiveness:

- Identification of programs that effectively influence human behavior change toward conscious avoidance (e.g., vessel speed reduction or shifting shipping routes to reduce ship strikes on whales)
- Identification of potential incentives for salmon recovery activities
- Research to enable routine use of dynamic habitat mapping and improve resolution to support targeted management strategies (e.g., for species avoidance or identifying habitats) including potential for remote sensing options and eDNA

Conclusion

Survey and interview participants working in areas throughout the West Coast suggested a need for greater clarity of effective strategies to implement coastal EBM and a stronger commitment from agencies and decision makers. Some areas have been working with an ecosystem perspective for decades, while others have only begun to effectively integrate social and ecological understanding to support holistic management design. In either case, challenges for EBM persist and the science described herein was identified to enable coastal managers to fulfill gaps and enable progress for EBM. The need for new strategies and tools to plan for and achieve EBM were commonly described needs in our West Coast surveys and interviews.

An overarching need on the West Coast was for science to improve the understanding of interconnections, both ecological and social, and to identify threats to ecosystems and human well-being. Respondents suggested research topics that would help shape innovative solutions to support sustainability and resilience in a region that supports a growing human population and threatened, but crucial, marine species.

Critical and Emerging Science to Support Ecosystem-Based Management

Pacific Islands

Ecosystem Science

- Climate change and land-use influences on habitat integrity
- Coral reef health and resilience

Socio-Ecological Science

- Co-development of science to improve the integration of traditional ocean uses into management
- Spatial tools and indicators to evaluate multiple ocean uses
- Restoration and conservation prioritization and effectiveness
- Aquaculture feasibility for economic growth and food security

Governance and Incentives

- Management structures and planning for sustainable and resilient communities
- Integrated fisheries management and links to ocean livelihoods
- Invasive and nuisance species management approaches

US Pacific Islands

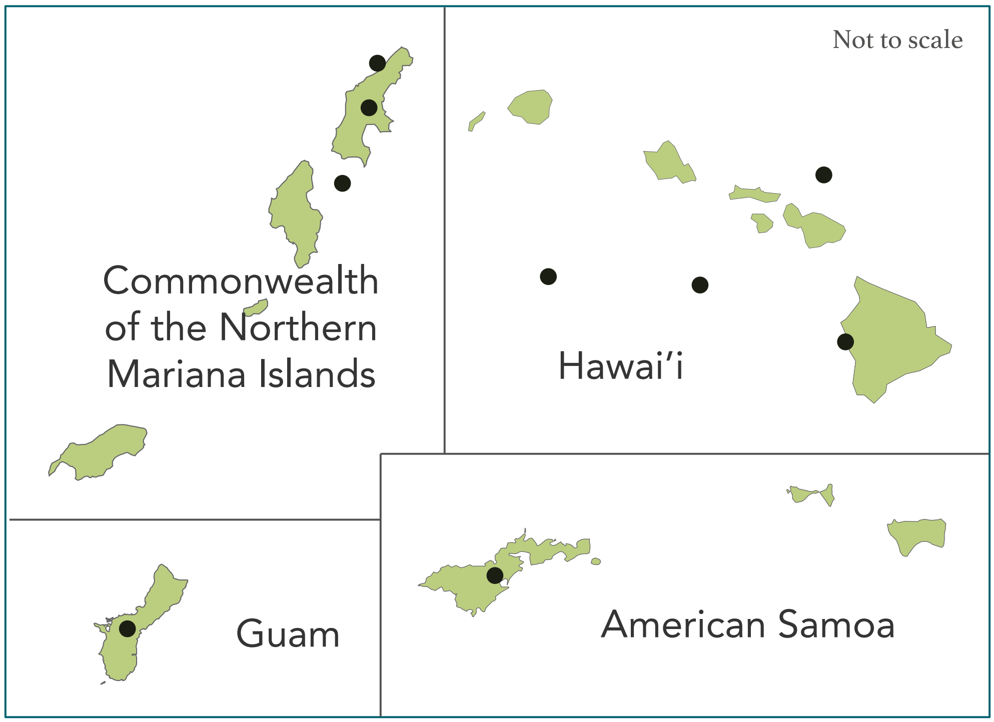
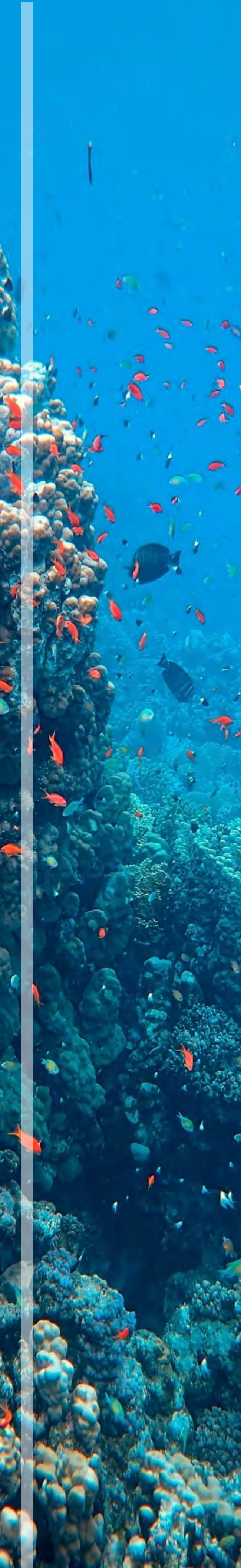


Figure 41. Pacific Islands region. Markers show the locations described in surveys and interviews.

The US Pacific Islands region described herein is made up of the territories within the US Exclusive Economic zone and includes the Hawaiian Islands, the Commonwealth of the Northern Mariana Islands (CNMI), Guam, the territory of American Samoa, and the US Minor Outlying Islands.



FEATURES OF EBM IN THE US PACIFIC ISLANDS

There is an apparent willingness for holistic, cooperative management strategies like EBM in the US Pacific Islands. Several regional planning and strategy documents have encouraged the larger, holistic approach that EBM encompasses (e.g., Helweg et al. 2017, American Samoa Ocean Planning Team 2018). Additionally, local communities have centuries-long histories of sophisticated understanding of ecosystems and sustainable use that have begun to see a revitalization (e.g., Hawaiian ahupua'a systems, traditional fish pond restoration) allowing them to better address problems of resource decline (Friedlander et al., 2013). Ecosystem-based management in the US Pacific Islands is supported by community involvement, cooperative efforts by agencies, and traditional knowledge and practices that recognize the social and ecological linkages in the islands' ecosystems. However, there is still a need for better integration of socio-cultural dimensions in regional management in order to increase the effectiveness of decision making and environmental policy development (Straza et al., 2018).

> "[T]he movement towards EBM is particularly welcome and familiar among Pacific Islanders."
>
> -Hawai'i Office of Planning 2016

The Integrated Ecosystem Assessment (IEA) program recently focused on the western coast of Hawai'i to identify ecosystem indicators and to develop an EBM approach (Gove et al., 2016). A suite of ecosystem indicators was used to assess the overall health and integrity of West Hawai'i coastal ecosystems (Gove et al., 2019) and a related workshop lead to a conceptual model of the social-ecological system to inform EBM (Ingram et al. 2018). The conceptual model is a visual portrayal of the opportunities and complexities of EBM in West Hawai'i but reflects challenges that are common throughout the entire Pacific Islands region. The study concluded that many of the most impacted ecosystem services were cultural attributes critical to human well-being but were not well integrated into the resource management processes (Ingram et al., 2018). The IEA program in the Pacific Islands region has thus far primarily used available demographic and economic data, fish species abundance, and commercial fishing and catch data as social indicators and describes work on human dimensions as ongoing (NOAA Integrated Ecosystem Assessment Program, 2019).

Perceptions of EBM in the US Pacific Islands

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Pacific Island region, we received seven survey responses and conducted follow-up interviews with three of these survey participants (Appendix A; Figure A3). Survey respondents self-identified their roles (Table 6A) and we identified affiliations from the email addresses provided in survey responses (Table 6B). All seven participants responded that EBM was a goal in their work and that they provide guidance for management decisions. Five respondents said that EBM was currently being used.

Table 6. Self-identified work roles (A) for Pacific Islands respondents and level of organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	2
Resource Manager & Policy maker	1
Resource manager only	3
Scientist & Resource manager	1
Total	**7**

B.

Organization	
Federal government	3
Non-governmental organization	1
University	1
Unidentified	2
Total	**7**

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. One respondent described three separate locations, thus the results and discussion that follow describe perspectives of EBM for nine Pacific Islands locations.

While the number of responses representing the US Pacific Islands region was substantially fewer than for most of the other regions in this report, the general priorities and views were similar to those of other regions. Respondents *somewhat* agreed that EBM was successfully being implemented in five of the nine locations described (Figure 42). No respondent strongly agreed. The majority of responses indicated that there were important science and communication needs that, if met, would enhance the likelihood of successful EBM implementation in the region (Figure 42).

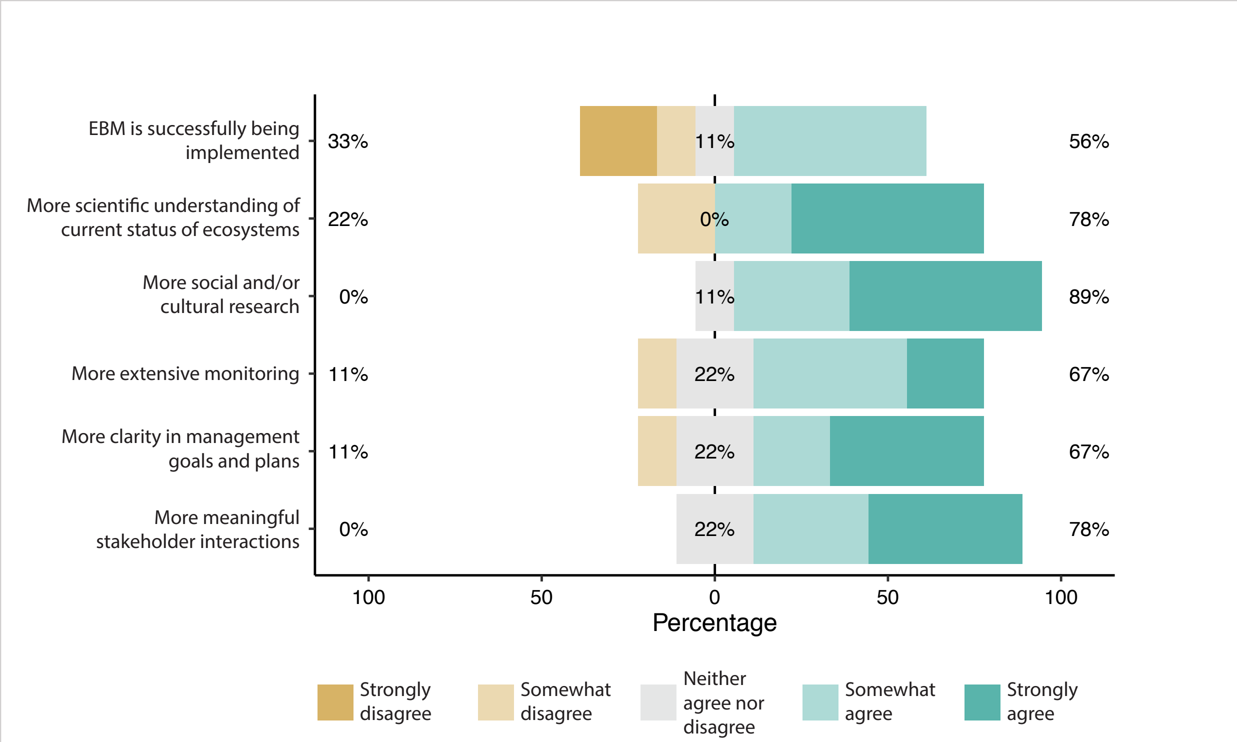


Figure 42. Practitioner opinions on needs before fully implementing EBM in locations in the Pacific Islands (SQ12, n=9). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad environmental and socioeconomic issues in locations in the Pacific Islands region, *water quality*, *habitat integrity*, and *coastal resilience* were most commonly rated as very or extremely important issues (Figure 43). The eight write-in responses listing additional issues that were very or extremely important for a location centered around common themes of social and cultural issues (e.g., ocean livelihoods, access equity, and economic development; 5), fisheries (i.e., food sustainability; 4), and tourism and recreation (3). We expected to see fisheries in these responses, which we had purposely omitted in order to encourage respondents to broaden their concerns. Results of our analysis for several regions, including the Pacific Islands, suggested that fisheries were regarded by many respondents as a distinct environmental concern within EBM.

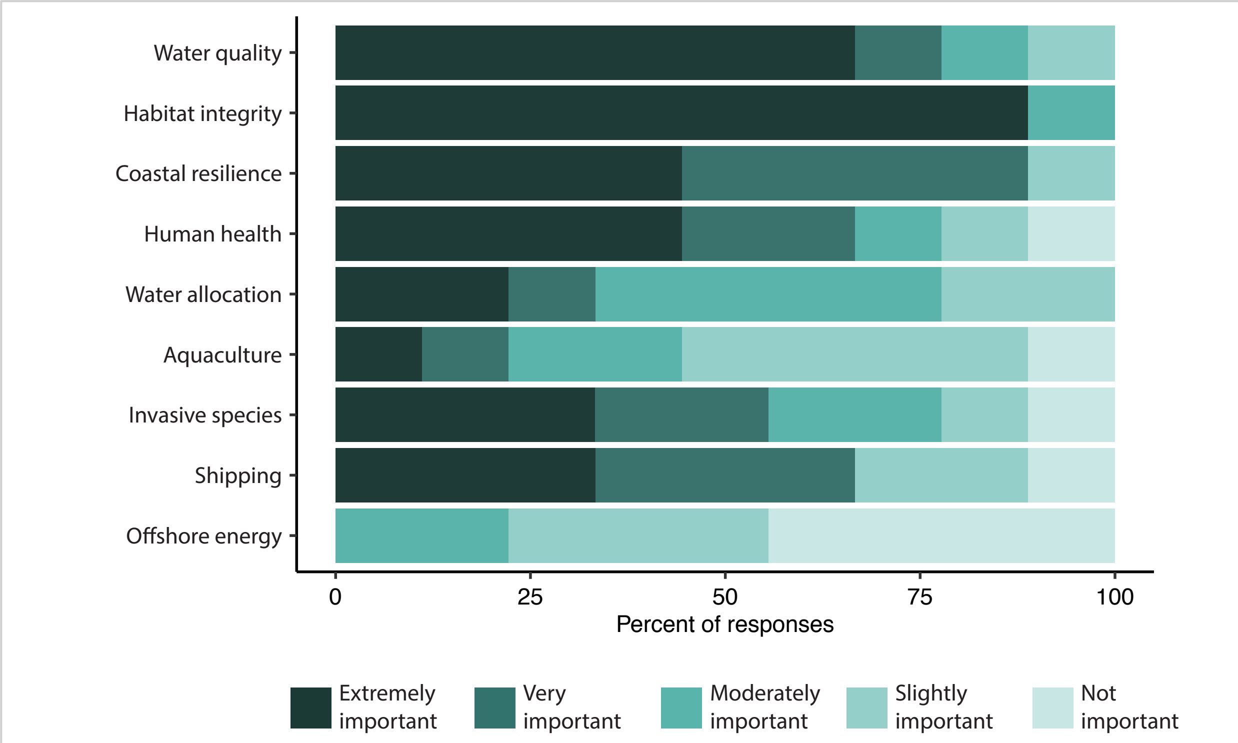


Figure 43. Priority issues as described by online survey respondents (SQ7, n=9).

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). Five of the six Pacific Islands respondents selected *evaluating tradeoffs, including understanding risk and uncertainty* as either the most or second-most difficult element of EBM to achieve (Figure 44). One manager working in Hawai'i suggested a better understanding of these and other tradeoffs would help to choose where limited restoration funds would be most effective. Evaluating tradeoffs was also a stated priority in several regional planning documents (e.g., Hawai'i Sea Grant 2017, Pacific Islands Fisheries Science Center 2019a, 2019b). Multiple ocean uses and complex collective dynamics in individual islands make understanding and accounting for tradeoffs particularly important in the Pacific Islands region.

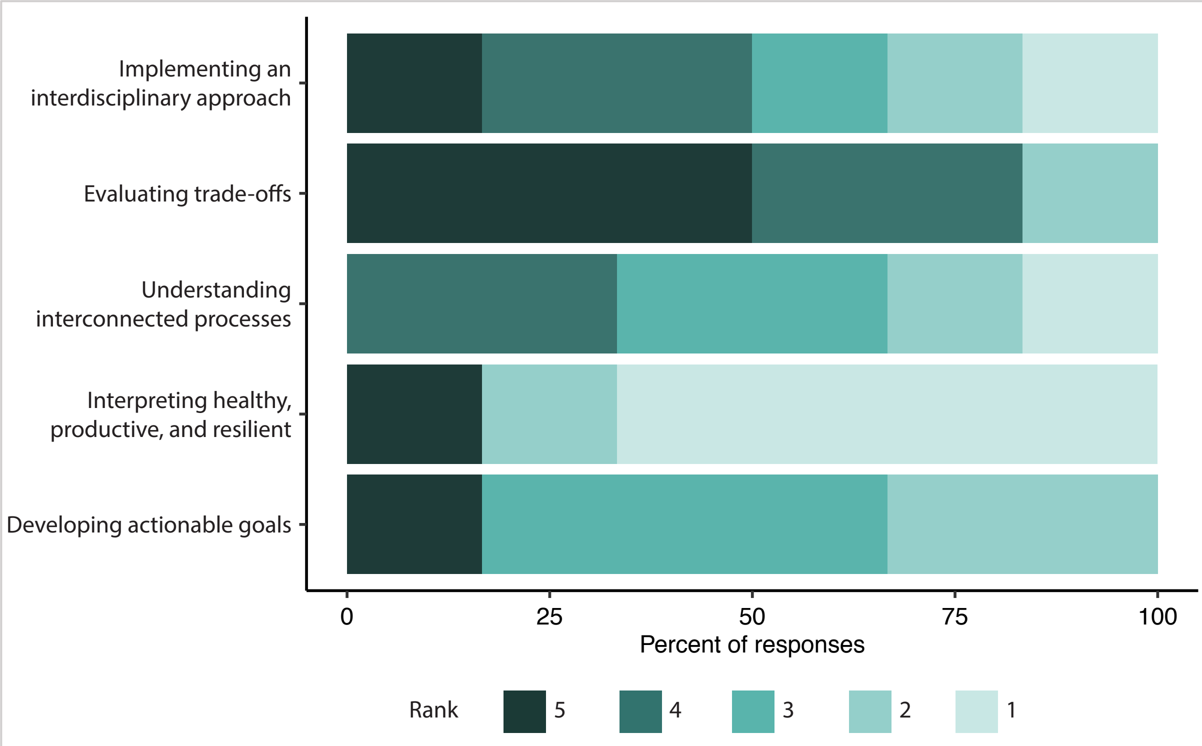


Figure 44. Perceived relative difficulty of EBM attributes, where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=6).

When asked to rate the influence on EBM (either supporting or hindering) of a list of management characteristics, the majority of online survey respondents agreed that scientific strategies and individuals are supportive of the EBM approach, but that institutional mechanisms and funding to implement EBM are still lagging (Figure 45). Respondents were more united in the view that existing scientific research and social engagement would support EBM planning and implementation goals, compared to more conflicted feelings about institutions. A responding resource manager believed that recent pressure from funders for interdisciplinarity in management has helped forward holistic strategies on the west coast of Hawai'i. They remarked that the more different the disciplines, the easier and more exciting the work because it revealed new approaches and potential solutions. Our results suggested similar enthusiasm for EBM strategies in other areas of the US Pacific Islands.

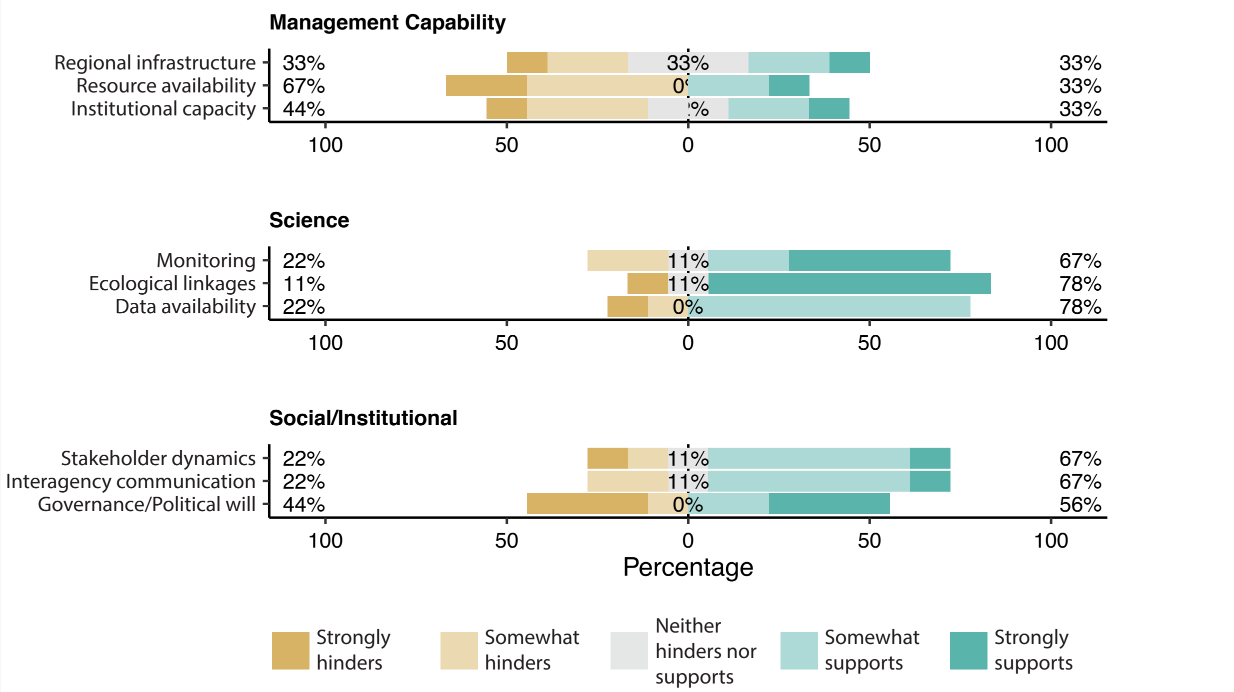


Figure 45. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11, n=9).

Responses to the question, *What is the biggest non-science barrier to EBM?* commonly referred to a lack of cooperation among organizations and limitations in financial resources dedicated to implementing an EBM framework. Five of seven responses referred to institutional will and processes that inhibit flexibility and cooperation (Figure 46). These results were similar to common concerns about the trustworthiness of institutions and government accountability that emerged during stakeholder interviews and surveys conducted in Hawai'i (Hawai'i Coastal Zone Management Program, 2019). Moreover, one respondent suggested that Pacific Islands research is underfunded when viewed on the national level because of the perception that research on the mainland results in a "bigger bang for the buck."

Figure 46. Coded themes of responses describing non-science barriers to EBM (SQ42, n=7) in locations of the Pacific Islands region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM* as an open-ended question. Fisheries issues were the most commonly mentioned and included points about socioeconomic sustainability (Figure 47). Socioeconomic research, including valuation of ecosystem services, was another common need expressed throughout sources (five out of six responses). Some examples were "viability of market stability from secondary take" and "measuring socio-cultural indicators of successful restoration." The other responses mentioned research into specific species and habitat needs and social science research topics related to engaging system beneficiaries and ensuring social justice in governance and decision making.

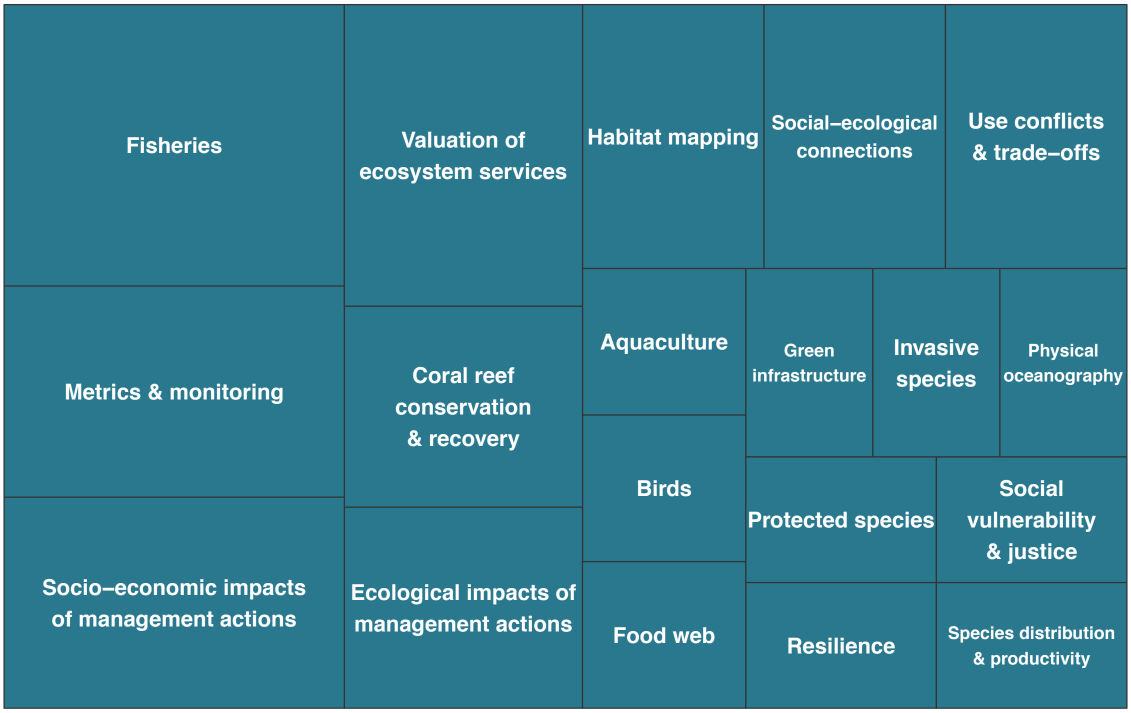


Figure 47. Topics appearing in survey responses describing critical science needs for EBM in the Pacific Islands (SQ10, n=6). Larger boxes correspond to more frequent mentions.

While survey participants working in the US Pacific Island were few, their responses and comments captured priorities similar to those described in the regional literature. In general, the survey results and interviews reflected a somewhat more positive view on existing EBM strategies than in some other regions. However, the Pacific Islands respondents had similar concerns as those in other regions about more effective use of knowledge in decision making and quantifying and managing socioeconomic impacts of management actions.

Critical and Emerging Science to Support EBM in the US Pacific Islands Region

One of the purposes of this project was to provide an update to the 2008 Prospectus (NOAA National Centers for Coastal Ocean Science 2008), a document that has helped guide regional coastal science research to address EBM and other management needs. Broad research priorities for the US Pacific Islands presented in the 2008 Prospectus included assessment and prediction of ecosystem impacts of development, climate change, and fishing. The guide called for improved understanding of ecosystem services provided by coral reef systems and factors influencing habitat and productivity. The 2008 Prospectus further described the need for science in the region to better understand the spread of aquatic invasive species and disease. The research needs identified in our analysis indicated that the subjects included in the 2008 Prospectus were still important priorities for science in the Pacific Islands. This effort updates and expands upon those recommendations.

Ecosystem Science

Survey responses and regional literature described a need for directed ecological research to better understand the effects of change on habitats and important species in the Pacific Islands region. Climate change and a dramatic increase in human population and development will require a better understanding of ecosystem dynamics and biophysical interactions to support coastal planning for resilience and sustainability. The 2008 Prospectus emphasized the need for science for modeling the connectivity patterns within ecosystems and among islands (NOAA National Centers for Coastal Ocean Science, 2008). Our analysis suggested that research within this realm is still needed to support regional model building to better understand and predict how coastal ecosystems are changing under increasing human pressures and changing climate drivers. Sources also highlighted the need for identification and characterization of critical habitats and ecosystem functions to help prioritize conservation strategies in the face of uncertainty.

When asked about the most effective strategy for encouraging EBM, a resource manager in American Samoa spoke of the importance of using the best available science alongside traditional ecological knowledge and anecdotal evidence, and to effectively communicate this information up to decision-makers. Another resource manager, in Hawai'i, responded to the same question by describing the rich connection that Pacific Islanders have to the land and expressed the importance of working closely with the local people that are most reliant on the ecosystem. The American Samoa Ocean plan also promotes enhanced integration of local and traditional ecological knowledge and scientific research in EBM planning (American Samoa Ocean Planning Team, 2018). The Hawai'i Coastal Zone Management program has included a dedicated initiative to gather and apply traditional ecological knowledge to guide the development of the updated Ocean Resource Management Plan (Hawai'i Coastal Zone Management Program, 2019).

ES 18. Climate change and land-use influences on habitat integrity

Research is needed to better characterize the physical connections within island watersheds that govern the transport of material and the effects of these fluxes on coastal habitats. Non-point source pollution has been a prevalent public concern in the region (Hawai'i Coastal Zone Management Program, 2019). Increased agriculture, changes in freshwater flow, and increasing pollutants coincide with a growing population and increasing development. Island ecosystems tend to thrive or fail together because they have particularly strong co-evolutionary interactions – effects on one (terrestrial and marine) area, such as habitat loss or non-native species invasions disrupting the food web, will impact linked species and ecosystems in other areas (Hills et al., 2011). Understanding these linkages and the potential for cascading impacts of habitat degradation is critical to EBM in the Pacific Islands.

Examples of science to support the advancement of EBM derived from surveys and regional literature included:

- Quantity and quality of groundwater needed to maintain ecosystem function and the influences of changes in groundwater dynamics (due to increased consumption, altered flow paths, and climate change) on near-shore aquatic habitats
- Species distribution (mapping and movement) to characterize changing habitat use
- Identification and mapping of ecologically sensitive areas and critical habitat
- Assessments of habitat vulnerability to support decision-making about future development that preserves ecosystem services

ES 19. Coral reef health and resilience

Ecosystem science is needed in the Pacific Island region to better understand the effects of local and large-scale stressors on coral reefs. Coral reefs throughout the Pacific Islands region are productive and biodiverse ecosystems that provide important economic, biogeochemical, and socio-cultural services (Kittinger et al., 2012). Substantial uncertainties exist in predicting the cumulative effects of decreasing water quality, climate change, and fishing pressures on coral ecosystem functioning (Harborne et al., 2017). Science that identifies local stressors could support mitigation decisions that would encourage ecosystem resilience in the face of less manageable external pressures like climate change (Anthony et al., 2015; Maynard et al., 2017).

Reef systems are particularly susceptible to the effects of global climate change. In the Pacific Islands, more frequent severe coral bleaching events, influenced by ocean acidification and increasing water temperatures, are projected to become annual events within the next 20 years (Leong et al., 2014). More frequent extreme events (e.g., tropical cyclones, ENSO) in Guam have contributed to declines of 30%-60% in live coral cover (Raymundo et al., 2019). A better understanding of the cumulative effects of climate change on coral loss could support the holistic management needed to maintain and improve ecosystem health (Gombos et al., 2010).

The following science is needed to help better understand coral reef health and resilience in the US Pacific Islands:

- Assessments of causes and vulnerability of reefs to coral disease, bleaching, and mortality

- Evaluation of the effects of sea level rise, changing circulation patterns, and temperature on the quantity and quality of habitat provided by reef ecosystems
- Understanding tools for predicting the cumulative effects (and relative importance) of watershed land use, pollutants, and climate change on coral reef systems to target local and regional protection and mitigation strategies

Socio-Ecological Science

Additional socio-ecological science is needed throughout the US Pacific Island region to identify opportunities to repair relationships among federal and state resource management agencies and Indigenous communities and to harness the willingness of local communities and stakeholders to participate in coastal planning and restoration. Our results suggested the willingness to participate and implement EBM is already there – the critical need is the development of methods to use it to further specific EBM actions. In eight of the nine locations described, survey respondents agreed that more social and/or cultural research was needed before EBM could be fully implemented (Figure 42). Resource managers, agency scientists, and community members in West Hawai'i similarly revealed a critical need to identify flows and feedbacks in social-ecological systems (Slater et al., 2017; Ingram et al., 2018). For example, in Guam, science is needed to identify and document community perceptions of acceptable resource management actions. In American Samoa, science is needed to describe local community use and attitudes and perceptions of potential protected areas and plans (Edwards et al., 2016).

Our sources also revealed the need for research to better anticipate the effects of climate change on combined changes in ecosystems and human behavior. Effects of climate change are expected to increase the stress on the social-ecological systems in the Pacific Islands, with potential to disrupt livelihoods and create conflict among EBM goals and user groups (Keener et al., 2018). The Pacific Islands Climate Science Center calls for "a holistic biocultural approach" to climate adaptation (Helweg et al., 2017). Because many coastal communities in the US Pacific Islands have long-standing traditions that have promoted long-term survival, institutions may benefit from applying such knowledge in decision-making. However, this knowledge cannot simply be woven in with formal ecosystem science. Rather, the knowledge holders need to be woven into the science-making process. This co-production of knowledge by researchers and knowledge holders can increase effectiveness and a sense of ownership of climate adaptation outcomes (Nalau et al., 2018). This cooperative approach may be particularly valuable in areas in the Pacific Islands where local, traditional structures still govern.

SES 16. Co-development of science to improve the integration of traditional ocean uses into management

Socio-ecological science is needed at the local and regional scale in the Pacific Islands to address the necessity for greater incorporation of traditional values into coastal management that is emphasized in regional planning (e.g., Edwards et al. 2016, Western Pacific Regional Fishery Management Council 2019). The geographic delineations of the Pacific Islands (Guam and CNMI are part of Micronesia; American Samoa and the Hawaiian archipelago are part of Polynesia) are a product of the distinct origins, cultures, languages, and colonization patterns of the earliest settlers of the islands. Native peoples of the Pacific Islands hold deep spiritual and cultural connections to land and sea, with the place-people connection being ancestral (Kana'iaupuni and Malone, 2010) and upheld in traditions still practiced. Regional planning documents demonstrate efforts to incorporate Indigenous communities and traditional ocean uses in decision making (e.g., Hawai'i Coastal Zone Management Program 2013, American Samoa Ocean Planning Team 2018), but our sources acknowledged a need for tools and methods to better integrate traditional values and practices into ocean management. The specific local and regional science that is needed to support environmental equity in resource accessibility will need to be co-developed with Indigenous knowledge holders.

The following socio-ecological science examples from surveys, interviews, and regional literature illustrate critical research that could support EBM:

- Cooperative documentation of Indigenous and traditional ecological knowledge and pathways and key junction points where this information could be integrated into coastal planning
- Derivation of social indicators of the vulnerability of fishing communities to local and regional stressors and climate change
- Evaluation of the resilience of culturally significant species and their roles as part of traditional ways of life
- Assessment of the socioeconomic value of ecosystems for providing traditional non-extractive uses and anticipated changes in values due to climate change

SES 17. Spatial tools and indicators to evaluate multiple ocean uses

Our surveys and interviews and regional planning documents identified the need for science to balance the multitude of activities on the coasts of the Pacific Islands. Economies of the US Pacific Islands depend greatly on activities such as tourism, fisheries, and US military installments and the relative dominance of activities varies by region. Tourism is the largest industry in Hawai'i and CNMI (Hawai'i Tourism Authority, 2015; CNMI Office of Planning and Development, 2019). Additionally, the economy of Hawai'i relies on US military and agricultural exports, and federal grants for environmental protection and infrastructure are an important source of income for CNMI. US national defense spending is a dominant portion of Guam's economy, and the economic importance of tourism has been growing in recent years (Guam Economic Development Authority, 2019). American Samoa depends largely on the tuna canning industry and is also exploring increasing tourism for economic diversification (Thero et al., 2010), including providing opportunities for enhanced recreational fishing (American Samoa Ocean Planning Team, 2018). These activities may complement or conflict with regional management goals for ecosystem health and sustainability and comprehensive evaluation of the tradeoffs of multiple ocean uses is needed to support EBM strategies and planning in the region.

The following are examples of research that could support activities like marine spatial planning, conservation prioritization, and sustainable economic enterprises:

- Identification and spatial mapping of the locations, overlaps, and hotspots of potentially conflicting uses of coastal and ocean environments (e.g., military use, shipping, tourism, traditional ocean uses)
- Effects of accelerating development (urbanization) on shorelines and associated near-shore ecosystems
- Identification of opportunities for tourism (including ecotourism) and methods to minimize environmental impacts of tourism activities and leverage them to provide financial support for conservation activities to build ecological and economic sustainability

SES 18. Restoration and conservation prioritization and effectiveness

Our survey and regional strategy documents described a need to better measure the effectiveness of restoration and conservation projects in the US Pacific Islands. One survey respondent specifically suggested social and cultural indicators be developed and used to assess the effectiveness of restoration strategies in CNMI. Other survey respondents and literature indicated similar needs to evaluate the range of human benefits that result from restoration and conservation projects. The more general theme of *impacts of management actions* was captured in 4 of the 6 survey responses describing critical science to support EBM. A common priority in management plans in the region was for integrated research across ecological and social science disciplines to evaluate outcomes of management strategies (e.g., Pacific Islands Fisheries Science Center 2019a, Western Pacific Regional Fishery Management Council 2019).

Examples of research to support evaluation and decision making for restoration and conservation as part of EBM were:

- Decision-support tools that generate ecological and socioeconomic outcomes that help prioritize habitat types and locations that should be targeted for restoration or conservation actions
- Analyses of the costs and benefits of alternative ecosystem restoration options to inform decision-making
- Improvement and expansion of how we characterize biophysical and social effects of restoration projects to allow for a more comprehensive evaluation of their effectiveness (e.g., through pilot projects or monitoring of social and ecosystem indicators)
- Assessment of the impacts of closures and catch limits on subsistence fishers (e.g., distributive justice research)
- Evaluation of feasibility, priority areas, and planning for erosion management and dune preservation to ensure coastal resilience

  Methods and planning for sea level rise, including evaluating uncertainties and tradeoffs among alternatives for mitigation and community adaptation (e.g., managed retreat, engineered solutions)

SES 19. Aquaculture feasibility for economic growth and food security

Aquaculture could provide opportunities for local economic development and more sustainable resource use, but site-specific research is needed to balance economic, community, and conservation goals that often create tradeoffs among stakeholders and ecological impacts

(Hawai'i Sea Grant, 2017). Food security is a major concern in the Pacific Islands region (American Samoa Ocean Planning Team, 2018). Currently, much of the food supply is shipped in by sea from the contiguous US states, creating vulnerabilities to supply disruptions and price fluctuations. Increasing local capacity for food production would help communities better withstand extended periods of detachment from the contiguous US states that could occur with natural disasters. Recent priorities for food security in the region have included goals for revitalizing traditional Hawaiian fish ponds (Hawai'i Coastal Zone Management Program, 2020) and for exploring off-shore aquaculture capacity (Hawai'i Coastal Zone Management Program, 2013; Hawai'i Sea Grant, 2017). Restoration of biocultural systems, such as traditional fish aquaculture practices, enhances social well-being and sustainability (Oleson et al., 2018).

The following examples of research to support decision making for aquaculture in the US Pacific Islands were identified from the surveys, interviews, and other documents:

- Regional assessment of the capacity, and evaluation of the techniques and feasibility, for restoration of traditional fish ponds to increase food security
- Tools to help determine place-based feasibility, optimal siting, and tradeoff analysis of aquaculture options, including consideration of short and long-term consequences of different types of aquaculture facilities and species
- Methods for determining the willingness and capacity for adding aquaculture infrastructure at the village and community levels
- Tools for comparing the ecosystem impacts of alternative aquaculture options (land-based, coastal, offshore)

Governance and Incentives

The US Pacific Islands each have different governance and environmental characteristics that will require nimble and creative approaches to increasing ecosystem and human community resilience. To support EBM throughout the US Pacific Island region, our review of survey and interview responses and regional planning documents suggested that institutions will need to expand efforts to identify opportunities to build capacity for EBM, enable and sustain cooperative management, and adapt to changing aquatic and terrestrial conditions.

According to surveys and interviews, partnerships were important catalysts in cases of successful EBM in the US Pacific Islands region. Both formal and informal partnerships for coastal management endure throughout the islands. For example, in Kāne'ohe Bay, partnerships among NGOs, academia, and government agencies were critical to successful management outcomes in coral reef recovery (Battista et al., 2016). The Pacific Islands Regional Planning Body was a partnership of federal and local managing organizations and completed one plan dedicated explicitly to EBM for American Samoa (American Samoa Ocean Planning Team, 2018) before the dissolution of all regional planning bodies with the 2018 repeal of the 2010 National Ocean Policy[6]. Responses also suggested that government management structures that limit these cooperative approaches were barriers to EBM. The most commonly described barriers to EBM in the US Pacific Islands were related to existing institutional structures (e.g., "lack of institutional flexibility," "institutional will" to do EBM, and "productive inter-agency cooperation"). For example, one respondent described a general lack of institutional flexibility to enable rapid changes to procedures and to enable redirection of resources and personnel that are needed for effective implementation of EBM. An interviewed respondent suggested that it seems like they are often just "dealing with the fires" and struggle to be more strategic with actions.

Continuous investment in monitoring was also seen as a necessary supporting activity to enable adaptive management to operate in the rapidly changing environments of the Pacific Islands (e.g., coral reef degradation). Adaptive management strategies that are integrated across ecological and social systems and may be more effective if they include support for social responses to change, such as self-organization and co-production of knowledge (Ayers and Kittinger, 2014), and innovative methods for community involvement and communication. Additionally, because use patterns and management often occur at the village level, impactful research and monitoring in the Pacific Islands will need to be carried out at a scale that facilitates effective decision-making at the local level.

GI 13. Management structures and planning for sustainable and resilience

Our survey and supporting planning and management documents suggested that developing and implementing climate adaptation strategies was among the leading priorities for the US Pacific Islands. Climate change in the Pacific Islands region is expected to have broad impacts on both the high, mountainous islands and on the low atolls and islands (Leong et al., 2014).

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[6] The 2010 National Ocean Policy (EO 13547) designated EBM as a national priority objective and established nine regional planning bodies for EBM planning. In 2018, Ocean Policy (EO 13840) removed the EBM objective and disbanded the regional planning bodies, but allowed federal support for existing regional ocean partnerships.

Throughout the region, respondents and planning documents expressed the need to consider managed retreat, passive survivability, and adaptive management (Hawai'i Coastal Zone Management Program, 2013; Helweg et al., 2017).

A critical exploration of governance structures and institutions was identified as an important need to understand how to deploy EBM to improve sustainability and resilience. For example, economic resilience could be supported through both resource diversification and conservation activities (Hawai'i Sea Grant, 2017). Additional research is needed to identify vulnerability and to enhance preparation for coastal hazards (Hawai'i Sea Grant, 2017; American Samoa Ocean Planning Team, 2018), as well as to prioritize "appropriate coastal development" (Hawai'i Coastal Zone Management Program, 2013).

The following are examples of science needed to support structures for EBM planning and sustainable development:

- Models of sustainable tourism development that could be used to promote economic resilience
- Strategies to support diversification of economic sectors to promote economic resilience in remote areas and villages (e.g., loan programs, public investments in supporting infrastructure)
- Models and tools to evaluate how policies, economic incentives, and regulations combine to promote deliberate management of existing and future nonpoint source pollution
- Strategies to improve the level of ecological and economic resilience in vulnerable communities while ensuring equity in resource provisioning

GI 14. Integrated fisheries management and links to ocean livelihoods

Marine resource harvesting was identified by resource managers, agency scientists, and community members in West Hawai'i as the strongest pressure on ecosystems (Ingram et al., 2018) and science to deal with the diversity of fishing activities and management was the most common research theme expressed in our survey (Figure 47). Sources stated the need to better understand how the dynamics of fisheries may affect, and be affected by, ecosystem change. Bycatch and concerns about protected species were other common topics related to fisheries in regional planning documents. Managers, fishers, and communities would benefit from science to support innovative technologies and techniques to avoid unintended interactions of fisheries with non-target species.

Fisheries are critical to the economy and identity of the US Pacific Islands. Commercial fishing in the US Pacific Islands is primarily focused on tuna species, though the fishing methods (e.g., longline, trolling, and purse seiners) and economic significance of the fisheries vary by location. Subsistence fishing is also important throughout the Pacific Islands. For two-thirds of Hawai’i surveyed recreational fishers, fishing for food was among the most important motives, with 36% saying their catch was an important part of their regular diet (Madge et al., 2016).

Interest and progress in EBM strategies in the Hawaiian Islands have partly been stimulated by intensive community involvement in fisheries and EBM efforts on the West Coast of Hawai’i (Tissot et al., 2009). The State of Hawai’i Coastal Zone Management program (2019) recognized that stakeholders were interested in a more holistic management perspective as part of coastal planning. A need for better science to understand and incorporate social and ecosystem values, other than commercial fishery outcomes, into fishery management was identified in multiple plans. Those values included concerns for non-commercial fishers’ motivations, catch, and efforts (Western Pacific Regional Fishery Management Council, 2019) and tradeoffs among stakeholder concerns about maintaining cultural practices and traditional livelihoods (Pacific Islands Fisheries Science Center, 2019b). A specific concern was that catch limits and area closures have disproportionately affected small-scale, local, and subsistence fishers. Greater community involvement in decision-making has been prioritized by some marine resource management agencies in the Pacific Islands, but local governance structures need to be better supported to achieve co-management strategies (Levine and Richmond, 2014).

The following research examples were suggested to promote equitable and sustainable fisheries management and to support EBM and decision-making:

- Documentation of key species interactions (overlaps) in time and space and co-usage of habitat to support fisheries management decision-making and regulations
- Habitat and food web links to variability in spatial distributions of important fisheries species
- New methods and technologies to reduce bycatch and other fishery interactions with non-target species so their effects on sustainable levels of harvest are known and quantified

- Methods to integrate subsistence and local, small-scale fishers' behaviors and needs in the formulation of equitable closures and catch limits (e.g., community-based subsistence fishing areas)
- Tools and techniques for building economic resilience within the fisheries to variation in stocks (abundance fluctuations and variation in species mixes)
- Strategies to revive and foster local fisheries community management structures

GI 15. Invasive and nuisance species management approaches

Aquatic and terrestrial invasive species are a prominent concern among coastal marine resource managers in the Pacific Islands. Island ecosystems are especially vulnerable to native species population decline, loss of biodiversity, and extinctions driven by biological invasions (Reaser et al., 2007). Invasive and nuisance aquatic species can threaten food supply, habitat integrity, and native species diversity. Terrestrial invasive species are also a concern for coastal EBM because of the intimate links between land and ocean in island ecosystems. The 2008 Prospectus identified a need to describe the extent and potential ecosystem impacts of invasive species on food webs. Our review of the survey and supporting documents suggested this research is still needed to better characterize the impacts of invasive and nuisance species across trophic levels.

Biofouling of vessels and ballast water is a major method for introduction of aquatic invasive species in the Pacific Islands (Davidson et al., 2014; United States Department of the Navy, 2015). While progress has been made in establishing procedures to avoid introduction of non-native organisms by vessels (e.g., quarantine protocols of the US Fish and Wildlife Service, biosecurity plans for Hawai'i and Micronesia), innovative technologies for both early detection and eradication of invasive species remain a critical science need. Agencies are also in need of economical and effective control techniques for established invasions (Hawai'i Department of Agriculture et al., 2016).

The following are examples of research that would support efforts for invasive species management, thus providing knowledge for EBM planning and implementation:

- Impacts of different types of invaders on the dominant trophic systems
- Implementation of innovative technologies for early detection and economically efficient technologies for mapping and control of invasion events

- Identify competitive interactions between native and invasive species to prepare for unintended consequences (e.g., new ecosystem structure) of control actions and removal

CONCLUSION

Our gathered information suggested that communities in the US Pacific Islands have long been implementing aspects of EBM. One interviewed resource manager described communities (stakeholders) in the Hawaiian Islands as “more savvy” about restoration needs because they can easily and directly see the changes around them. Our survey supported this idea, as stakeholder buy-in was not mentioned as being a primary barrier to EBM, which was a major contrast to other regions. However, there is still a need for progress in integrating the needs and values of local communities in resource management and policy making to ensure equity and independence. According to our synthesis, the predominant research needs to enhance EBM in the region were related to understanding the ecological and socioeconomic implications of management decisions and anticipating the multiple interacting effects of ecosystem change. Specific areas of interest to survey respondents included coral reef habitat integrity and improved understanding of ecological connectivity to predict effects of anthropogenic activities and allow for effective local and regional planning for resource sustainability and resilience. Greater investments in the integrated science described herein could build capacity for more complete EBM implementation in the region.

Critical and Emerging Science to Support Ecosystem-Based Management

Alaska and US Arctic

Ecosystem Science

- Climate change impacts on coastal ecosystems

Socio-Ecological Science

- Effects of climate change on subsistence and traditional ocean uses
- Methods to understand and balance multiple ocean uses

Governance and Incentives

- Cooperative management strategies for sustainability and equity

ALASKA AND US ARCTIC

Figure 48. Alaska and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The Alaska and US Arctic region discussed here includes the coastal and marine ecosystems of Alaska. Five large marine ecosystems are delineated for the region, including the waters of the Gulf of Alaska, the Chukchi, Beaufort and East Bering Seas, and the Aleutian Islands. The effects of climate change are being seen in the Arctic region more quickly than anywhere else in the world. The Arctic region has been experiencing more frequent anomalous weather events and changing climate conditions which threaten to drastically alter the region's ecosystems.

Features of EBM in Alaska and the US Arctic

Marine and coastal management in Alaska have made important strides toward EBM over the last two decades. The North Pacific Fishery Management Council established a committee in 1996 to explore and develop an ecosystem-based management approach (Witherell et al., 2000). Recent projects for Alaska fisheries science have been working toward EBM with regionally scaled and integrated modeling to assess species vulnerability and evaluate management scenarios with predicted changes in habitats and species ranges (e.g., Spencer et al. 2019, Hollowed et al. 2020). Management agencies in Alaska have also acknowledged the value of local ecological knowledge (LEK) and traditional ecological knowledge (TEK) systems to help generate relevant research questions to inform management, serve human communities, and ensure equity (National Research Council, 2002). Though there is room for improvement in implementation strategies, resource management in Alaska has benefited from processes of co-production of knowledge for decades (Robards et al., 2018). These efforts toward integrated biophysical science and management goals for ecological and social well-being in Alaska are key elements of EBM.

Perceptions of EBM in Alaska and the US Arctic

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Alaska and US Arctic region, we received five survey responses and conducted follow-up interviews with two of these participants. Survey respondents self-identified their roles (Table 7A) and we identified the level of organizational affiliation from the email addresses provided in survey responses (Table 7B). All five survey participants agreed that EBM was a goal in their work, that EBM is currently being used, and that they provide guidance for management decisions.

The number of respondents representing the Alaska and US Arctic region was substantially fewer than for most of the other regions in this report. We report the survey results in this section, just as in each of the other regions, but we note that with so few respondents, these results can be considered more anecdotal, and may not be an accurate reflection of broader perceptions of EBM in this region.

Table 7. Self-identified work titles (A) for Alaska respondents and level of organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	2
Scientist & Resource manager	0
Scientist, Resource manager, & Policy maker	0
Resource manager only	1
Policy maker only	0
Did not identify as above	2
Total	**5**

B.

Organization	
Federal government	3
State government	0
Non-governmental organization	0
University	1
Unidentified	1
Total	**5**

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. One respondent described two separate Alaska and US Arctic locations, thus the results and discussion that follow describe perspectives of EBM for six locations.

Responses in four of the six locations described in the online survey agreed that EBM is successfully being implemented (Figure 49). Most respondents also agreed that there were important social and cooperative improvements needed to enhance the likelihood of successful implementation of EBM (Figure 49). One interviewed resource manager working in the Gulf of Alaska commented that a limited state capacity for social science means that there is a lack of understanding of local communities' needs and values. Another source suggested that social science research could be better leveraged across fisheries and climate scientists and managers to support EBM decision making.

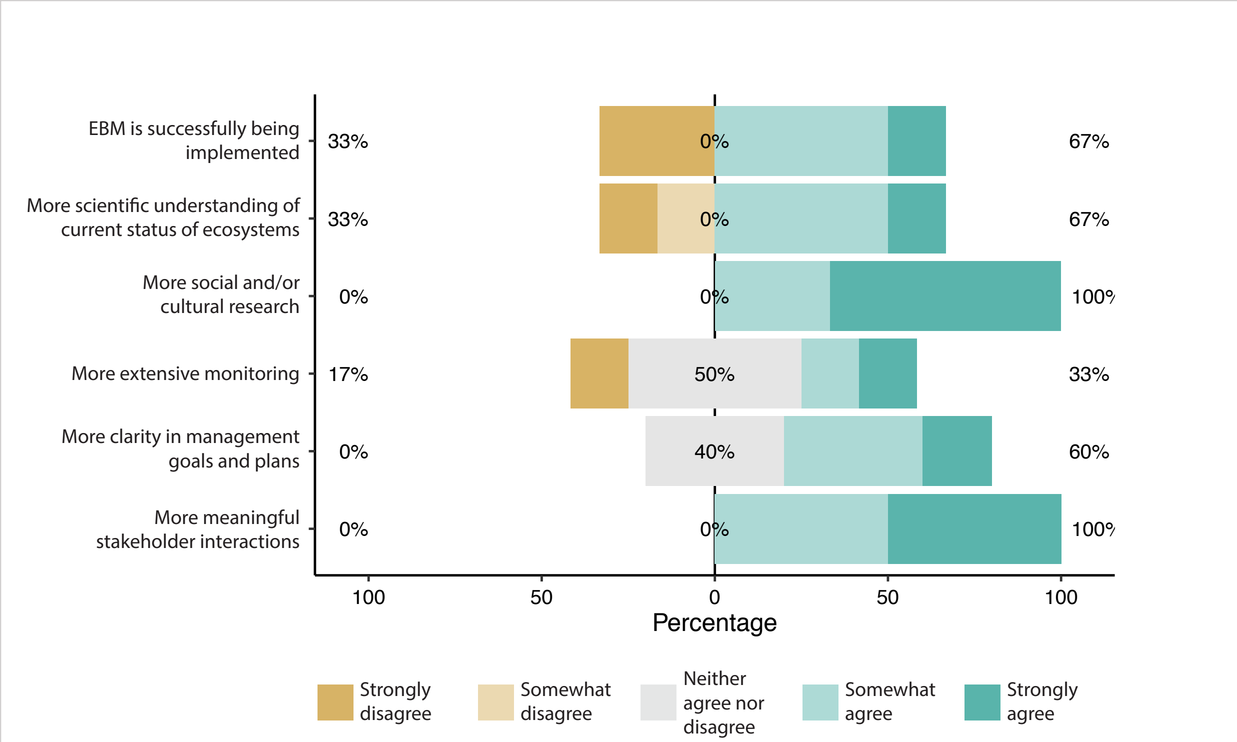

Figure 49. Practitioner opinions on needs before fully implementing EBM in locations in Alaska and US Arctic (SQ12, n=6). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad environmental and socioeconomic issues in Alaska and the US Arctic, all except one response deemed coastal resilience, habitat integrity, human health, and shipping as very or extremely important (Figure 50). Four write-in responses listed additional issues that were very or extremely important for a location. All four respondents described social or cultural issues (e.g., subsistence resource use, Tribal consultation). Sea ice was also included in three of the responses, and climate change was listed in two responses.

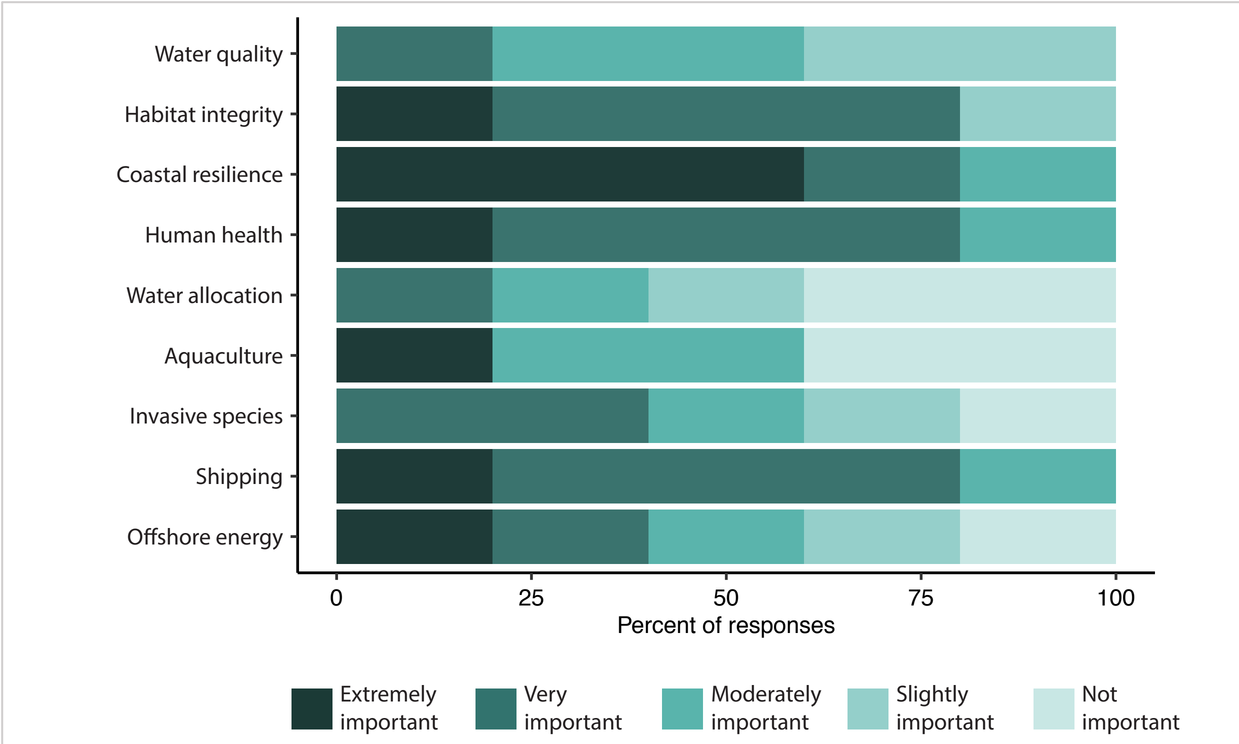

Figure 50. Priority issues as described by online survey respondents (SQ7, n=5).

The respondents had some divergent views on barriers and opportunities for EBM in Alaska and the US Arctic. We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). In the survey responses, *interpreting healthy, productive, and resilient ecosystems* was ranked as the most difficult by two of the five respondents. Another two respondents ranked *implementing an interdisciplinary approach* as the most difficult element of EBM, while two others ranked it as the simplest (Figure 51). One interviewed individual, who described their job as working in an interdisciplinary capacity in Alaska fisheries, suggested that "the science is really there" for understanding tradeoffs, interconnected processes, and developing goals in the Gulf of Alaska but interpreting and implementing the science was the challenge. In their experience, "Many managers don't prioritize integration of non-economic social science" to support strategies for co-management and co-development of knowledge. However, another interviewed respondent (ranking interdisciplinarity as the 3rd most difficult of the named elements of EBM in the survey) said "having interdisciplinary teams" has been the most effective strategy for encouraging EBM in Alaska. In their experience, social-ecological systems thinking has been the key to successful EBM and has allowed them to draw from local knowledge to fill gaps in conventional scientific data.

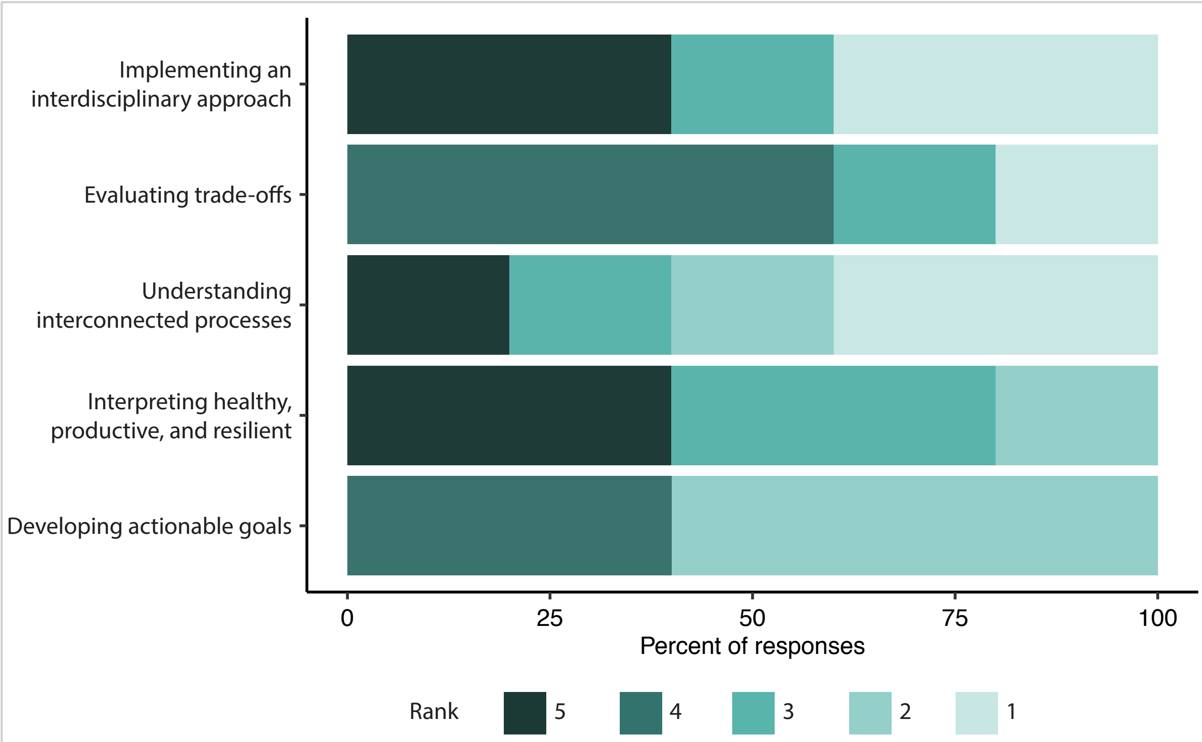

Figure 51. Perceived relative difficulty of EBM attributes, where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=5).

When asked to rate the influence on EBM (either supporting or hindering) of a list of management characteristics, participants responded that existing science is sufficient to support the EBM approach in Alaska and the US Arctic (Figure 52). Aspects related to management capability were more commonly perceived as hindering EBM in the region. Responses to the open-ended question, *What is the biggest non-science barrier to EBM?* provided further details (Figure 53). Two of the four responses referred to a lack of financial resources. One comment noted a lack of institutional processes that value traditional ecological perspectives and a lack of personnel trained to incorporate Indigenous knowledge holders in ecosystem science and policy making.

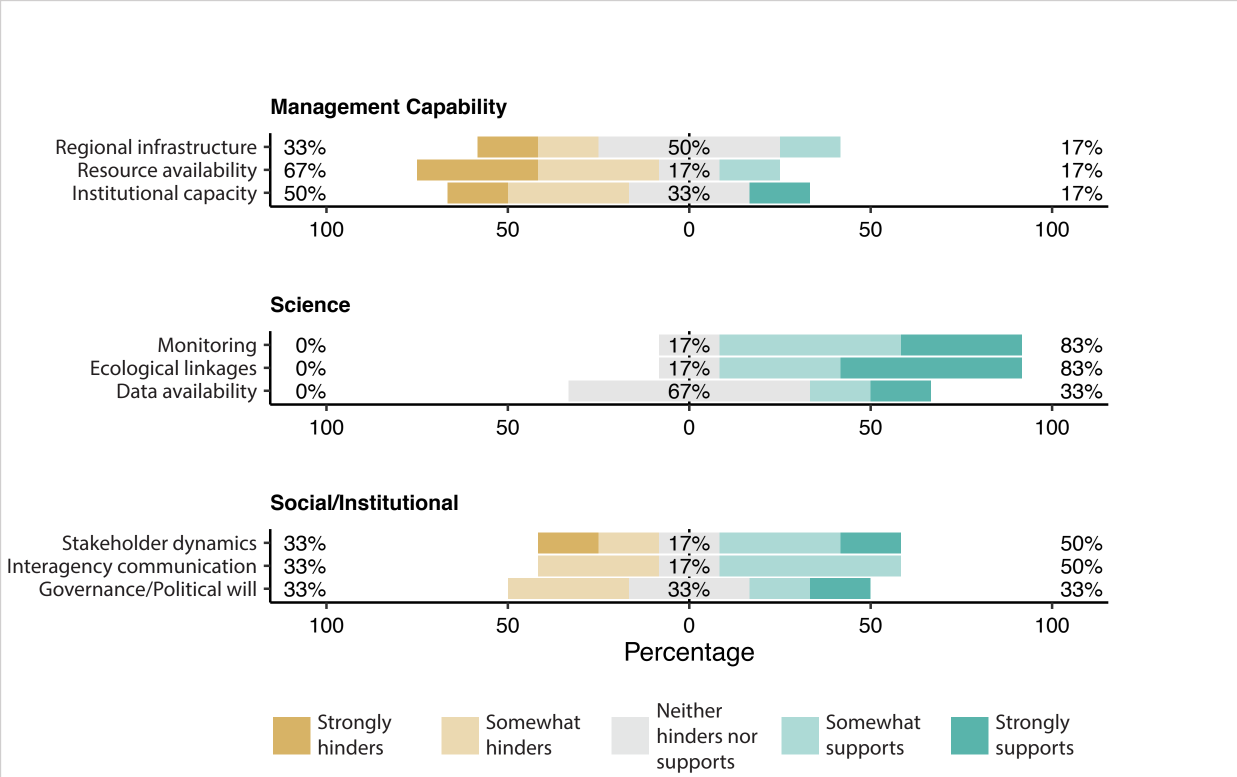

Figure 52. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11; n=6).

Figure 53. Coded themes of responses describing non-science barriers to EBM (SQ42, n=4) in the Alaska and US Arctic region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. All four Alaska responses described a need for science to improve understanding of social-ecological connections, with two respondents noting the need for more effective knowledge exchange (Figure 54). Two responses specifically mentioned understanding the effects of climate change on human communities and the ocean resources they depend upon.

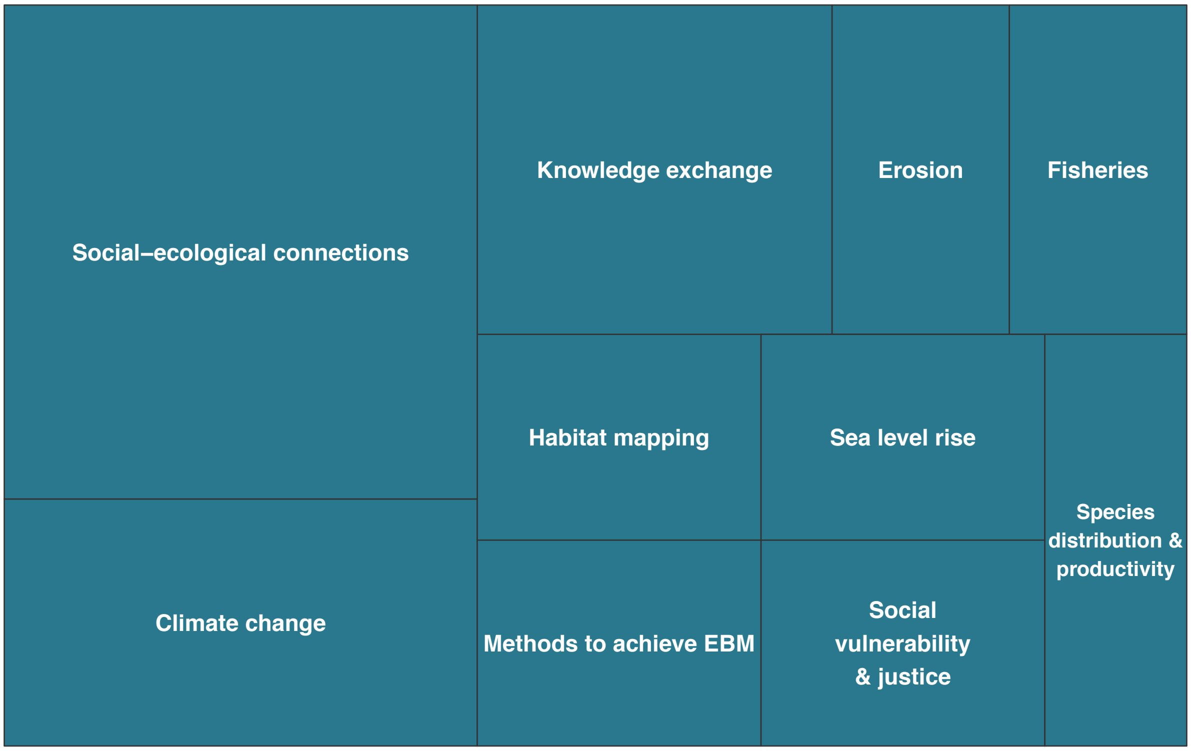

Figure 54. Topics appearing in survey responses describing critical science needs for EBM in Alaska and the US Arctic (SQ10, n=4). Larger boxes correspond to more frequent mentions.

While survey participants working in Alaska and the US Arctic were few, their responses and comments captured priorities similar to those described in the regional literature. In general, the survey results and interviews reflected the perception of EBM as a valuable management effort and it is gaining support among decision makers. Respondents noted that financial and personnel resources were still insufficient for attaining the broad ecosystem understanding needed for EBM and linking that knowledge to local and regional socio-economics.

Critical and Emerging Science to Support EBM in Alaska and the US Arctic Region

Ecosystem Science

Survey responses and regional reports described a need for ecosystem science to better describe how climate change will influence ecosystem and resource availability (e.g., for subsistence and commercial fisheries). Evidence suggests that major shifts in ecosystem structure and conditions are already underway in the Arctic seas and community wellbeing and adaptation depend on understanding the coming changes (Huntington et al., 2020). For example, ocean acidification is more rapid and extensive in the Alaska marine region than anywhere else in the US, disturbing both ecosystem function and fisheries (Sigler et al., 2017). The loss of sea ice is affecting habitats, as well as animal behavior and movement. These impacts are altering food webs and resource availability, and increasing erosion, flooding, and storm surge risks for coastal communities (USGS, 2015; Markon et al., 2018).

"We don't have the science to understand how to be successful when we make goals."

-Responding Scientist

ES 20. *Climate change impacts on coastal ecosystems*

The overarching science need that was expressed in surveys, interviews, and regional strategy documents in Alaska and the US Arctic was the characterization and prediction of ecosystem alterations due to climate change occurring in both the short and long term. A major objective for regional planning for Alaska is to understand and manage for climate-driven change in ecosystems and marine resources (Dorn et al., 2018). Sources suggested a need for forward-looking tools to understand climate extremes and potential ecosystem tipping points. However, there is also still a lack of foundational data on existing populations and processes controlling ecosystem function and productivity (NOAA Fisheries, 2017).

Examples of ecosystem research needed to support EBM were:

- Projections of shoreline change and erosion (especially northern coast) and assessment of effects on coastal ecosystems
- Baseline ecological data (populations and biophysical processes) to support ecosystem models and forecasting
- Effects of ocean acidification on critical habitats and food webs (e.g., cold-water corals, pteropods, an important food resource for juvenile salmon)
- Ecosystem effects of sea ice loss, such as cascading effects on food webs
- Identification of potential consequences of climate change on species ranges and predator-prey interactions

Socio-Ecological Science

The need for research to better understand socio-ecological connections in Alaska was expressed by every survey respondent and was a common priority in regional planning and strategy documents. For example, there is a need for more quantitative information of the socio-economic effects of management decisions on commercial and subsistence fishers (NOAA Fisheries, 2017), as well as understanding and predicting the abundance and distribution of subsistence and commercially important species (Alaska Sea Grant, 2017). An interviewed scientist suggested a critical need for socio-ecological science to support innovation in coastal infrastructure in changing extreme environments. They gave the example of communities that are accustomed to winter storms that blow snow across the ice. They described that, with ice loss, the storms now blow water, which current infrastructure is not designed to withstand.

This participant acknowledged a need for local capacity-building for relocation and adaptation, including predicting the impacts of climate change on coastal communities.

SES 20. Effects of climate change on subsistence and traditional ocean uses

Our survey and interviews and our review of regional priority and strategy documents identified the need to improve understanding and integration of cultural connections and traditional practices into management decisions in Alaska, especially as communities are faced with impacts of climate change. Recent work on place-based conceptual models highlighted the myriad of complex social-ecological connections that can exist in communities and local fisheries that emphasized the value of co-production of knowledge for effective integration of the social and ecological components of ecosystems for EBM in Alaska (Rosellon-Druker et al., 2019). Resource managers in Alaskan regions are working to better integrate Indigenous communities and traditional ocean uses into decision making (e.g., Sigler et al. 2016, NOAA Fisheries 2019). However, surveys and interviews suggest there are still important gaps in research on community needs and values, impacts of management decisions, and resilience of traditional and subsistence ocean uses.

The following cross-cutting research would enhance socio-ecological science for EBM in Alaska and the US Arctic:

- Characterization of subsistence use and traditional harvest, including evaluation of sustainability of harvests and vulnerability to effects of climate change and anthropogenic activities (e.g., pollutants)
- Potential impacts of climate change on food security and community viability
- Methods to predict and adapt to changing sea ice coverage and weather patterns

SES 21. Methods to understand and balance multiple ocean uses

Our analysis identified the need for science to help managers balance the multitude of activities in Alaska and the US Arctic region. Alaska's marine resources are critical to socioeconomic wellbeing at local, regional, and national levels. These resources are likely to be substantially altered with climate change, providing both challenges and opportunities for future management. For example, loss of sea ice will open up new shipping routes, and increases in resource extraction or tourism would increase different types of shipping traffic. Coastal management in the region will need to anticipate and account for interrelated ecosystem changes to avoid negative impacts on marine species, human communities, and local and regional economies.

EBM priorities for multiple ocean uses in the US Arctic and Alaska included:

- Population effects of commercial fisheries and adaptation of harvesting to changing species distributions resulting from climate change
- Technologies to improve aquaculture production and economic viability
- Disruptions to marine mammal communication and navigation, and predation, foraging, and movement of fish caused by anthropogenic marine noise (e.g., vessels, seismic oil and gas exploration, military sonar)
- Effective methods of mitigating disease, predation (orcas), and other impacts to marine mammals

Governance and Incentives

To support EBM throughout Alaska and the US Arctic region, our review of survey and interview responses and regional planning and strategy documents suggested that institutions will need to expand their commitment of resources (both financial and personnel) to build capacity for EBM with cooperative and adaptive management strategies for changing conditions. A major acknowledgment for Alaska's coastal and marine environments that appeared throughout our analysis was the need to do a better job of integrating local communities into management decision making and policy development (e.g., Raymond-Yakoubian et al. 2017).

"We are adaptive people."

-Responding Scientist

Long-term planning for resilience in Alaska must occur alongside short-term adaptation (IPCC, 2019). The scientific infrastructure in Alaska is well-equipped to achieve and apply ecosystem research, particularly in data-rich regions like the Southeastern Bering Sea and the Gulf of Alaska. However, there is still uncertainty about the cumulative effects of climate change and how or when they will manifest the need for human community adaptation, including relocation of some communities. One interviewed scientist noted the adaptability of Alaskans but remarked that policy must allow for flexibility in management to ensure food security and enable adaptation strategies that may include community relocation.

Research is needed to support “climate-ready” strategies that capture the range of management alternatives (Sigler et al., 2016). An interviewed scientist stated the priority for “building better communities” requires better science on the impacts of climate change and how to build resilience for communities and economies. Survey responses stressed the need for science to address ecosystem threats unique to the US Arctic region (loss of sea ice, new shipping routes, food insecurity). Science is needed to explore economic opportunities for diversification of Alaska’s maritime businesses (Alaska Sea Grant, 2017) and improving practices of knowledge co-production to recognize opportunities for adaptation (Robards et al., 2018). Proactive adaptation in cooperation with coastal communities in Alaska will be important for maintaining social and economic resilience (Markon et al., 2018).

GI 16. Cooperative management strategies for sustainability and equity

The need for integrated knowledge development and its application to management objectives and actions appeared throughout our analysis. A resource manager who responded to the survey noted that the Bering Sea is a well-studied ecosystem and that the critical science for EBM is using that scientific knowledge alongside traditional and Indigenous knowledge to inform management. Similarly, according to another respondent, the critical need for EBM was the development of “strategies for co-management and co-knowledge” to interpret and implement existing science. While the value of LEK and TEK to ecosystem understanding has recently been better acknowledged in the region, strategies to effectively co-produce knowledge and ecosystem management are still needed. Science can contribute by evaluating what cooperative methods are successful and by developing best practices that apply social science research and learning from experience. Some initial work has been done to integrate LEK and Western science to develop social-ecological conceptual models and thereby improve interpretation of local ecological systems (Rosellon-Druker et al., 2019). Building trusted partnerships includes ensuring against the misuse or misappropriation of Indigenous knowledge (NOAA Fisheries, 2019e) and acknowledging different ways of knowing. A key consideration moving forward will need to be thorough regard for these knowledge holders’ priorities and fair deference to their sovereignty.

Science suggestions to improve the operation and effectiveness of governance included:

- Strategies to develop trusted partnerships and techniques for co-production of knowledge (e.g., collaborative modeling, consensus-based management structures)
- Creating institutional incentives to meaningfully engage and integrate traditional and local ecological knowledge into management
- Strategies to encourage environmental justice and safeguard Indigenous rights in regional decision making

CONCLUSION

Every source we approached in the Alaska and US Arctic region expressed the requirement for science and management to consider the needs and values of local and Indigenous communities. An interviewed respondent commented that EBM strategies, in general, were likely easier to achieve in Alaska than in other regions because it has been a part of management since early statehood. They suggested that Alaska has been implementing aspects of holistic management and has led the management field in recognizing the substantial value of Indigenous knowledge in supporting and progressing EBM. Conversely, another survey participant communicated that Alaska Native populations have historically been marginalized by conventional science and coastal resource management decision making. Our analysis determined there is still substantial room for improvement in management strategies and policy development that ensures the inclusion and equality of Indigenous communities. Further, the Alaska and US Arctic region is facing dramatic ecosystem changes with climate change and associated challenges to the human communities that rely on them. The science described herein will be needed for EBM approaches to predict and respond to the cascading effects on socio-ecological systems.

Critical and Emerging Science to Support Ecosystem-Based Management

Laurentian Great Lakes

Ecosystem Science

- Habitat and food web dynamics
- Pollutant cycling and impacts on ecosystems

Socio-Ecological Science

- Socioeconomic analyses to support prioritization for restoration and conservation projects
- Human health effects of pollutants
- Nutrient management effectiveness and innovation

Governance and Incentives

- Tools to improve lake level management strategies
- Shoreline resiliency planning

Laurentian Great Lakes

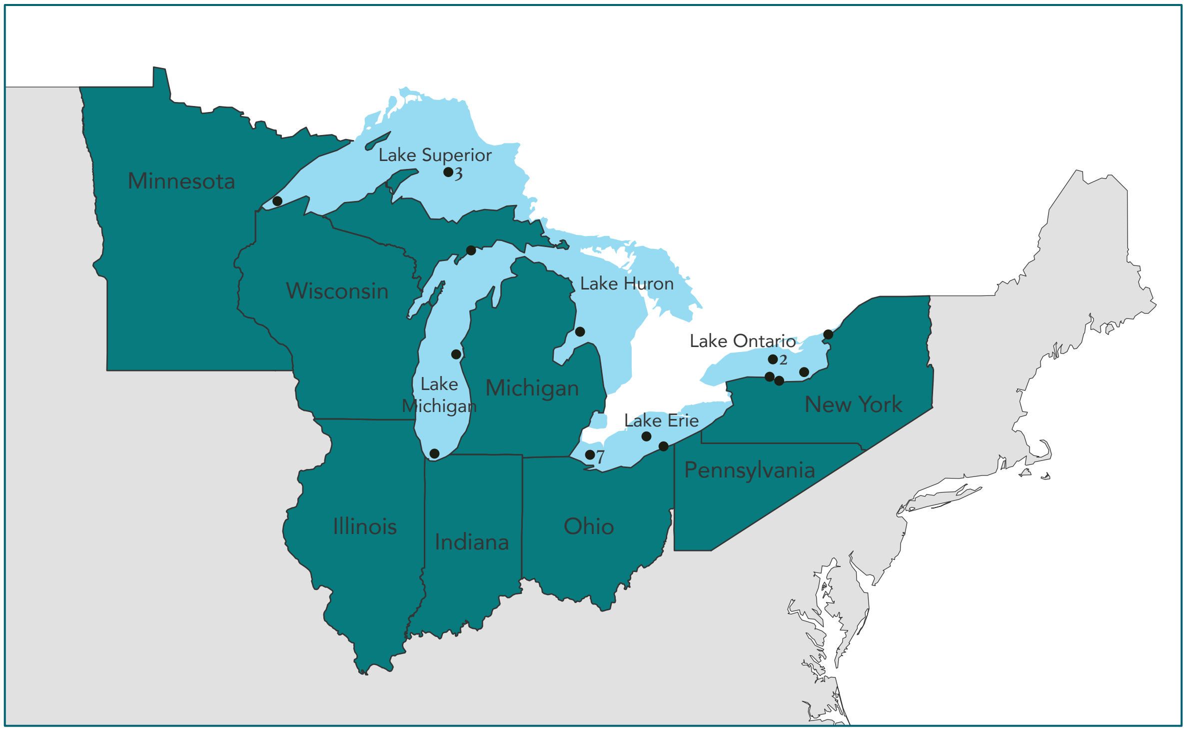

Figure 55. Great Lakes region and locations described in surveys and interviews. Numerals indicate locations that were described by more than one respondent.

The Laurentian Great Lakes are an interconnected freshwater system at the boundary between the US and Canada. A drainage area over 520,000 km^2 includes parts of Illinois, Indiana, Michigan, Minnesota, Ohio, Pennsylvania, and Wisconsin, and the Canadian province of Ontario, requiring interstate and international cooperation for management. Lakes Superior, Michigan, Huron, Erie, and Ontario contain about 20% of the Earth's surface freshwater. The lakes have large bays, extensive wetlands, and islands in a humid continental climate.

Features of EBM in the Laurentian Great Lakes

The Great Lakes region was among the earliest adopters of coastal EBM in the US. The Great Lakes ecosystems have been heavily impacted since European settlement beginning in the 1700s, and in the mid-20th century, the realization occurred that water quality in the Great Lakes was in crisis (Guthrie et al., 2019). Environmental degradation in the region had become apparent and a shift to more holistic ecological science was encouraged in the Great Lakes Water Quality agreement of 1978; by the 1980s, an ecosystem science approach was underway in the Great Lakes Basin (Harris et al., 1987). Early experiences in the Great Lakes identified important institutional characteristics and cooperative planning needs to successfully implement EBM, such as stakeholder involvement and the commitment of leadership (Hartig et al., 1998). The New York Ocean and Great Lakes Ecosystem Conservation Act of 2006 prioritized the integration and enhancement of EBM strategies for managing human impacts on coastal ecosystems (New York State Senate, 2006). More recent plans demonstrate a continuing commitment to EBM approaches to enhance restoration and support resource sustainability in the Great Lakes (e.g., Illinois-Indiana Sea Grant 2017, University of Wisconsin Sea Grant College Program 2018, Guthrie et al. 2019).

Perceptions of EBM in the Laurentian Great Lakes

We conducted a national online survey (Appendix B) to elicit perceptions of EBM among scientists, managers, and/or policy makers involved in coastal resource management. We asked them to assess a) current level and effectiveness of EBM implementation; b) research gaps; and c) pressing challenges going forward. For the Great Lakes region, we received 30 survey responses and conducted follow-up interviews with three of these survey participants. Survey respondents self-identified their roles (Table 8A) and we identified organizational affiliations from the email addresses provided in survey responses (Table 8B). Twenty-five respondents agreed that EBM was a goal in their work, and 20 of those said that they provide guidance for management decisions. Twenty-two respondents said that EBM was currently being used in their work.

Table 8. Self-identified work titles (A) for Great Lakes respondents and organizational affiliations (B) as identified from survey responses.

A.

Role	
Scientist only	15
Scientist & Resource manager	1
Scientist, Resource manager, & Policy maker	2
Resource manager only	3
Policy maker only	2
Scientist & Policy maker	2
Did not identify as above	5
Total	**30**

B.

Organization	
Federal government	3
State government	3
Non-governmental organization	3
University	7
Unidentified	14
Total	**30**

We asked respondents to identify and describe attributes in one or more geographic areas that could benefit from EBM. Four respondents described two separate locations, thus the results and discussion that follow describe perspectives of EBM for 34 locations.

The majority of respondents in the Great Lakes region expressed a need for additional scientific research (ecological and social), improved stakeholder interactions, and improved planning and management, suggesting that there were opportunities for critical research to further advance EBM. On the question in the survey about whether EBM was being successfully implemented, about 1/3 agreed, about 1/3 disagreed, and just fewer than 1/3 were neutral (Figure 56). The lack of majority opinion could reflect the heterogeneous environmental characteristics and diversity of concerns throughout the region. The lakes range from the oligotrophic Lake Superior to the productive and more industrialized coast of Lake Michigan and the more urbanized and farmed watershed of shallow Lake Erie (Waples et al., 2008). These characteristics give each lake unique drivers and vulnerabilities and thus there is a strong lake-specific aspect to the needed science and EBM.

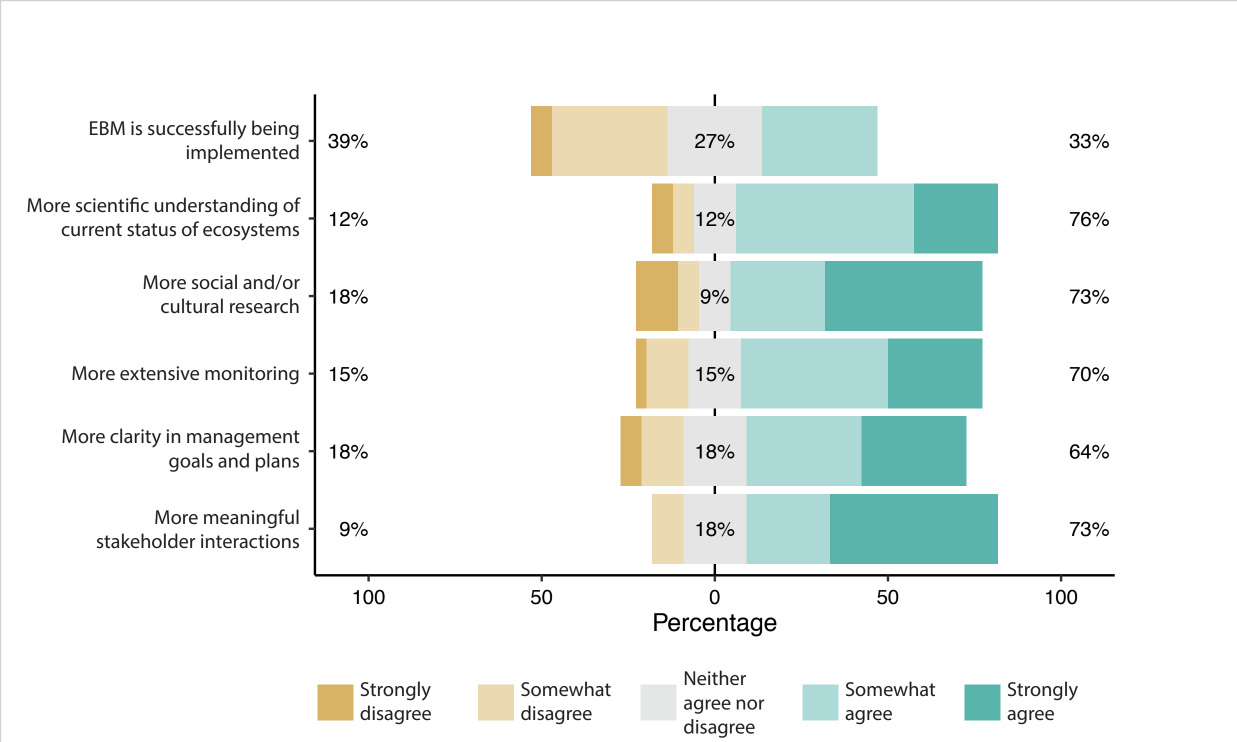

Figure 56. Practitioner opinions on needs before fully implementing EBM in locations in the Great Lakes (SQ12, n=33). The marginal numbers indicate the percentage of respondents who somewhat or strongly (dis)agreed with the statement. The central number is the number who were neutral. Thus, the three numbers sum to 100%.

When asked to rate the importance of nine broad issues in the Great Lakes region, *water quality*, *habitat integrity*, *coastal resilience, human health, and invasive species* were most commonly rated as very or extremely important issues (Figure 57). Each was rated very or extremely important by greater than 70% of the survey respondents. In the 19 responses to the option to provide additional issues deemed very or extremely important for their location, the most common replies were related to climate change (5 comments) and flooding (4 comments). We also intentionally omitted climate change from the list under the rationale that its effects would be captured within the listed issues. Results of our analysis for several regions, including the Great Lakes, suggested that this topic was regarded by many respondents as a distinct environmental concern within EBM.

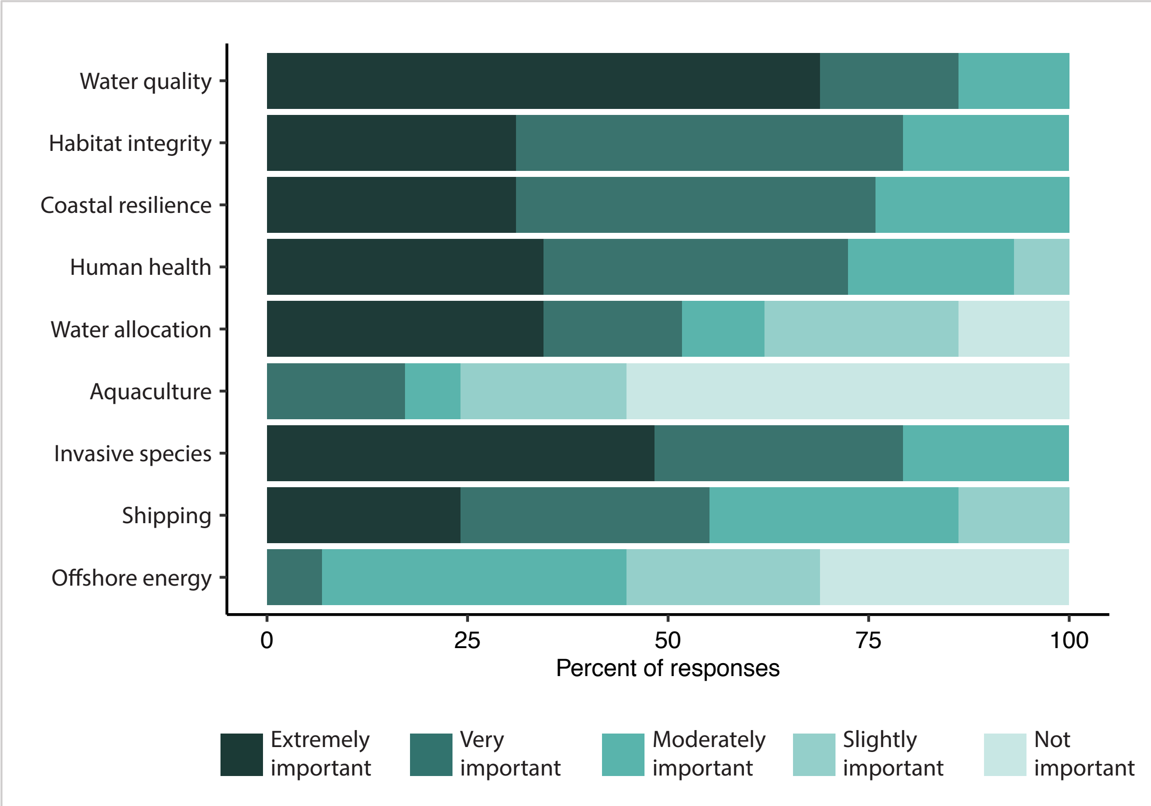

Figure 57. Priority issues as described by online survey respondents (SQ7, n=29).

We asked respondents to rank the difficulty of achieving EBM elements, as derived from our operational definition (see above). *Developing actionable goals* and *implementing an interdisciplinary approach* were perceived as among the most difficult to achieve. *Interpreting healthy, productive, and resilient ecosystems* was more commonly regarded as relatively simpler (Figure 58). These results were similar to those for other regions. Interviewed respondents in the Great Lakes region each had different perspectives on the most difficult element of EBM but described similar reasons for their ranking. A participant that ranked *implementing an interdisciplinary approach* as most difficult explained the struggle for different disciplines and organizations to understand the priorities of one another. A respondent that selected *evaluating tradeoffs* as the most difficult explained that conflicts among stakeholders can inhibit decision making and progress. Another interviewed individual ranked *understanding interconnected processes* as most difficult. They described a need for greater open-source and discoverable data to connect information sources. A common theme in these responses was communication among individuals and organizations playing a role in ecosystem management and decision making.

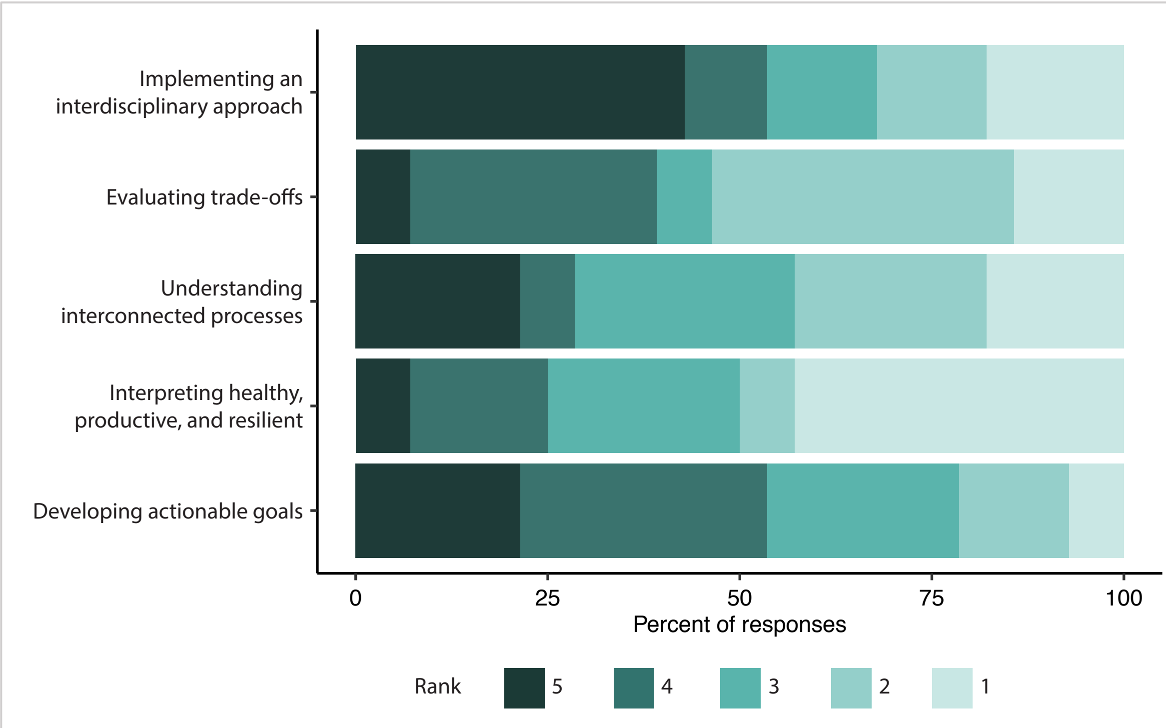

Figure 58. Perceived relative difficulty of EBM attributes where 5 is the most difficult to achieve and 1 is the easiest to achieve (SQ40, n=28).

Online survey respondents generally agreed that the science being done in the Great Lakes region is supportive of EBM (Figure 59). One responding scientist, concentrating on harmful algal blooms in western Lake Erie, believed that the existing science is sufficient to support an EBM approach and conveyed that the critical needs are mostly in building stakeholder support for actions and in the effective implementation of management strategies. Respondents also described a general need for a better understanding of the ecological and social effects of management actions. Survey responses suggested that a lack of tools (e.g., integrated models, communication techniques) to support the effective development and prioritization of management strategies may be a contributing barrier to putting current scientific knowledge into action.

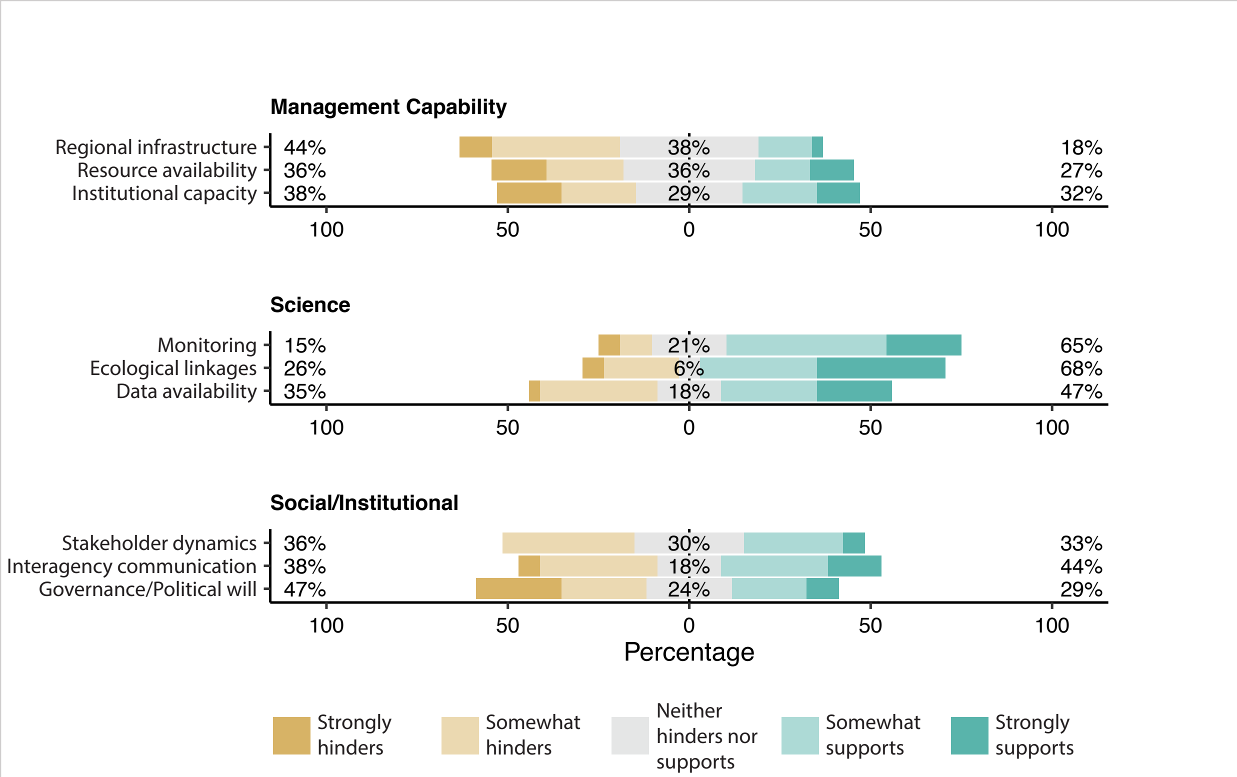

Figure 59. Respondent ratings of the influence on EBM planning and implementation of nine key elements derived from review of plans and strategy documents (SQ11, n=34)

In responses to the survey question, *What is the biggest non-science barrier to EBM?* issues related to existing institutional structures appeared in eight of 24 comments (Figure 60). In context, respondents described complications related to jurisdictional boundaries and a lack of flexibility and communication across agencies. Our analysis also suggested that managers were struggling with the most effective ways to improve coordination of stakeholder and management objectives. Seven of 24 responses referred directly to stakeholder buy-in as a barrier to EBM (Figure 60). When asked about the key ingredient that would encourage EBM in the region (IQ4), all three interviewees discussed the need for better communication, with equity and outreach being other common themes. A clear emphasis on effective stakeholder relationships for EBM in the Great Lakes was acknowledged at least two decades ago (e.g., Hartig et al. 1998). However, half of all survey respondents *strongly* agreed that more meaningful stakeholder interaction is needed to effectively implement EBM in the Great Lakes (Figure 56).

Figure 60. Coded themes of responses describing non-science barriers to EBM (SQ42, n=31) in the Great Lakes region. The size of words is relative to the frequency of the code.

The survey asked respondents to *List the critical scientific information still needed to support or enable EBM*. The Great Lakes capture and concentrate stressors from large and diversely used watersheds. This was reflected in the responses that expressed a wide range of issues that need additional research to implement EBM (Figure 61). Identifying the effects of anthropogenic pollutants on water quality was the most common general science need expressed in survey responses. Eight of 27 survey responses regarded a need for a better understanding of pollutant cycling, including that of nutrients, microplastics, and other chemical contaminants. Science regarding nutrients and harmful algal blooms was a salient concern for Lake Erie, in particular. Research describing habitat change, flooding, and shoreline change was more commonly described for the other lakes.

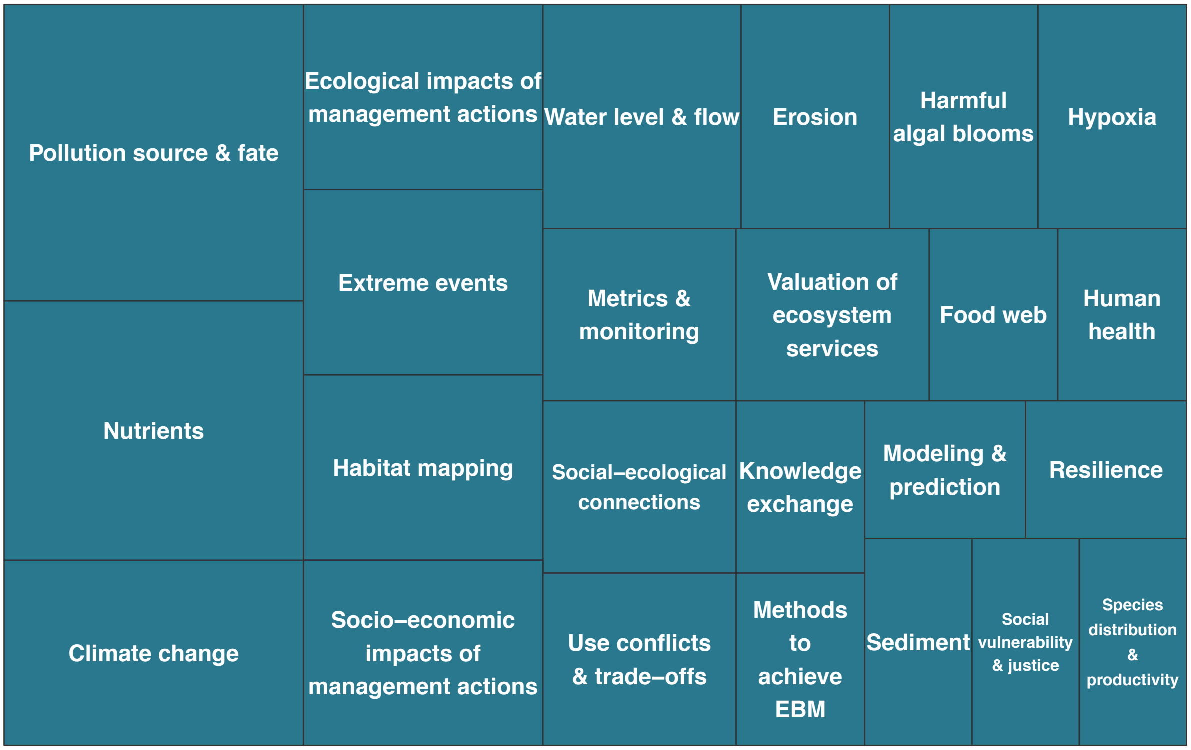

Figure 61. Topics appearing more than once in survey responses describing critical science needs for EBM in the Great Lakes region (SQ10, n=28). Larger boxes correspond to more frequent mentions.

Critical and Emerging Science to Support EBM in the Laurentian Great Lakes Region

Ecosystem Science

Geography, geology, and water residence time vary among the Great Lakes, as does the lakes' sensitivity to anthropogenic impacts (Waples et al., 2008). An overarching science need that was identified for the Great Lakes region was to improve understanding of differences in the ecosystems and their linkages among the lakes. One source suggested that regional science has often overlooked the importance of connecting waterways. The Great Lakes are connected by a series of rivers and ultimately drain through the St. Lawrence River to the Atlantic Ocean. Although much has been learned, the ecological relationships within and among the interconnected lakes are changing with types of human uses of the watershed and lakes and due to climate change. The following science suggestions compiled from the survey, interviews, and regional plans are intended to promote understanding of these interconnections and how they change in order to provide a firm basis for designing and implementing EBM strategies in the region. This new knowledge could also help develop innovative tools to support regional needs for interoperable information systems, improved strategic monitoring, and adaptive management (e.g., University of Wisconsin Sea Grant College Program 2018, Canada-United States Collaboration for Great Lakes Water Quality 2020).

ES 21. Habitat and food web dynamics

Survey responses and regional reports both described a need for new science to characterize the spatial variation in productivity and habitats within each of the Great Lakes, which could be applied to improve understanding of vulnerabilities and to prioritize restoration and other management efforts. Important habitats within lakes need to be identified and mapped, and local risks to habitat integrity (e.g., invasive species impacts) need to be evaluated (Great Lakes Restoration Initiative, 2019). A better understanding of food web linkages was a common priority of reports that discussed the Great Lakes region (e.g., Environment and Climate Change Canada and US EPA 2016, 2018a, 2018b, 2019, Moen et al. 2019). At the basin scale, research is needed to quantify and project how climate change will impact habitats and how these changes in habitats will, in turn, result in changes in species distribution (Great Lakes Compact Council, 2019; International Joint Commission Science Advisory Board, 2019).

The following are examples of ecosystem science that would improve the understanding of food webs and habitats to facilitate EBM strategies:

- Relationships between pelagic and benthic food web and water quality dynamics
- Spatial variation of lower food web productivity and how it relates to the spatial distribution of preferred aquatic habitat types (e.g., rocky substrates and depositional areas)
- Models and data analyses for identifying ecosystem thresholds and for developing estimates of the proximity of the response variable (e.g., food web) to tipping points
- Seasonal and interannual spatial distribution maps of prey species (e.g., stable isotope/diet studies) to understand the linkages between the lower and upper food webs and to support development of multispecies models
- Characterization (spatial and temporal) of the structure and energy pathways of ecosystems to support prioritization of restoration and protection areas
- Quantification of the Influences of invasive species on habitat and predator-prey interactions
- Efficient methods for early detection and rapid response of aquatic invasive species
- Ecological effects of the loss of winter ice cover occurring with climate change

ES 22. Pollutant cycling and impacts on ecosystems

Water quality was deemed extremely important by 63% of respondents in the Great Lakes region and water quality/contamination was among the highest-ranked issues in a stakeholder survey by Michigan Sea Grant (Michigan Sea Grant, 2016). Water quality differs among the five main lakes, partially as a result of varying levels of anthropogenic influence and also due to variation in their sizes, depths, watershed land use, and water residence times (Waples et al., 2008). Urban and agricultural development and industry-related activities have contributed to water quality degradation throughout the region. Remobilization of legacy pollutants from lake sediments, bioaccumulation of mercury in food fish, present-day pollutant run-off, and harmful algal blooms are significant human health and water quality concerns in the Great Lakes. Restoration of water quality in the Great Lakes is a binational priority formalized in the Great Lakes Water Quality Agreement.

Research to better identify and quantify pollution (including nutrients) sources and fate was the most common critical science described in our survey responses for the Great Lakes (Figure 61). Regional literature also prioritizes science to describe pollutant cycling (Environment and Climate Change Canada and US EPA, 2019) and to identify the potential impacts on water quality, habitat, and species (The Great Lakes and St. Lawrence Collaborative, 2019). While multiple reports and literature sources identified important science needs for tackling relatively well-studied pollutants (e.g., mercury, nutrients, bacteria), some emerging contaminants were also mentioned in our survey. For example, one survey respondent expressed frustration that the problem of perfluoroalkyl substances (PFAS)[7] has only recently become a focal concern. Sources described a major need to improve sampling and analysis techniques for perfluorooctanoic acid and perflourooctanesulfonic acid (PFAS no longer produced in the US), and for replacements to PFAS, to better understand contaminant cycling and its ecosystem effects (University of Wisconsin Sea Grant Institute, 2018; International Joint Commission Science Advisory Board, 2019; Murray et al., 2019). Another surveyed scientist noted that microplastics are known to be a pervasive pollutant in the Great Lakes, but their sedimentation and mobilization characteristics are almost entirely unknown. More generally, chemicals used in detergents, personal care products, and pharmaceuticals are of growing concern for Great Lakes water quality (The Great Lakes and St. Lawrence Collaborative, 2019) and little is known about their individual and cumulative ecological effects.

[7] PFAS are persistent, bioaccumulative, and toxic chemicals used in household and industrial products, including firefighting foam, waterproof clothing, non-stick cookware, toothpaste, and pesticides (Murray et al., 2019).

Examples of science needed to better understand ecosystem effects of contaminants included:

- Assessments of water quality vulnerability from mobilization of contaminants by erosion (e.g., legacy mining waste)
- Effective use of sentinel species to monitor the prevalence of contaminants
- Determination of the distribution and mobilization rates of microplastics and their resulting exposure and effects on biota
- Understanding biogeochemical thresholds of nutrient and contaminant runoff, recycling, and remobilization, particularly in the context of legacy effects
- Nearshore nutrient dynamics and their role as triggers of algal blooms to focus and track tributary and watershed management efforts to reduce loadings.
- Delineation of the different sources, pathways, and cycling of emerging chemicals of concern in the environment (e.g., PFAS, microplastics, polycyclic aromatic hydrocarbons)
- Relationship of lake level management on the biogeochemical mobilization of sediment-based mercury

Socio-Ecological Science

Socio-ecological science is needed throughout the Great Lakes region to identify opportunities for greater participation by managing agencies and stakeholders in EBM and to promote sustainable and equitable resource use. While 72% of survey participants agreed that more social and/or cultural research was needed before EBM could be fully implemented, only seven of the 27 responses to the inquiry, *List the critical scientific information still needed to support or enable EBM*, provided specific ideas on research needs for socio-ecological science. However, when responses from our survey were considered alongside the follow-up interviews and regional priorities in plans, some important needs for research into socio-ecological connections emerged.

> "How does behavior change happen?"
>
> -Responding scientist

One respondent we interviewed in the Great Lakes discussed the need for science to include the human perspective. They suggested that the key ingredient for EBM is broad participation and buy-in to the process. EBM is strategic management that takes a holistic approach toward sustainable and resilient social-ecological systems, including ensuring that diverse priorities are incorporated in management plans. Regional planning documents acknowledge the value of traditional ecological knowledge and note the need to increase the integration of such knowledge into planning for the Great Lakes (Environment and Climate Change Canada and US EPA, 2018a; Canada-United States Collaboration for Great Lakes Water Quality, 2019; Michigan Sea Grant, 2019). Socio-ecological science that identifies human priorities for the ecosystem services provided by healthy Great Lakes ecosystems can improve communication about management needs and engage stakeholders in shared problem-solving; these will lead to effective implementation of EBM.

SES 22. Socioeconomic analyses to support prioritization for restoration and conservation projects

Survey responses and planning documents in the Great Lakes region conveyed the need for new science to explore socioeconomic vulnerabilities related to shoreline change (e.g., The Great Lakes and St. Lawrence Collaborative 2019), water supply (e.g., Great Lakes Compact Council 2019), and invasive species (e.g., Great Lakes Commission 2017, Minnesota Sea Grant 2018). There was a focus on identifying cross-cutting science priorities to serve future restoration projects and planning (Great Lakes Compact Council, 2019; Great Lakes Restoration Initiative, 2019), such as the determination of the socioeconomic benefits of improved water quality (University of Wisconsin Sea Grant Institute, 2018) and enhancement of collaborative research to support participatory efforts for setting EBM goals (Michigan Sea Grant, 2016). While quantifying benefits to humans is a useful component of EBM, such strategies are complemented by social science evaluation of the type of management actions that are most compatible with the values and activities of individuals and businesses.

The following examples, compiled from survey responses, interviews, and regional strategy documents, illustrate needed socioeconomic research:

- Market and non-market valuation of impacts of aquatic invasive species
- Identification of EBM problems and locations where coastal restoration and conservation targeted at resiliency are most likely to be successful in the long term

- Methods and analyses to characterize and quantify the socioeconomic benefits of improved water quality to enhance prioritization and communication of management actions

SES 23. Human health effects of pollutants

Pollution source and fate was the most common theme in survey responses describing critical science to support EBM (Figure 61) and pollution was frequently mentioned in interviews when people were asked about any unlisted issues of importance for the region. Pollution was also most often mentioned as the most significant problem in the Great Lakes in a recent binational poll of over 4,000 regional residents (Great Lakes Water Quality Board, 2018). A safe source for drinking water and food fish are major priorities in the Great Lakes. The lakes provide drinking water for greater than 48 million people. Presently, fish consumption must be restricted due to chemical pollutants that accumulate in fish tissue (e.g., polychlorinated biphenyls and mercury).

Survey responses suggested research to understand toxicity and human health effects of chemical and physical contaminants that are thus far not well described. For example, there are substantial potential human health effects of PFAS, but few studies on human exposure in the Great Lakes (Murray et al., 2019). Regional strategy documents also prioritized research to better understand human health effects from exposure to contaminants (e.g., Minnesota Sea Grant 2018, The Great Lakes and St. Lawrence Collaborative 2019). Potential human health effects of harmful algal blooms are also a persistent concern in the Great Lakes. In 2014, the drinking water supply for 400,000 people was shut down because of high microcystin concentrations stemming from a major algal bloom in Lake Erie.

Examples of priority research topics included:

- Exposure of humans to contaminants of concern in drinking water and contact recreation by socio-demographic categories
- Potential toxicity and human health effects of chemical pollutants (e.g., PFAS, pharmaceuticals)
- Bioaccumulation of microplastics by fish and the resulting risks for advisories and warnings related to limitations on human consumption of fish
- Improving predictions of the magnitude and persistence of human exposure to toxicity levels during harmful algal bloom events and the associated health effects

- Social and health implications of warnings to avoid fish consumption or water contact (e.g., unexplored tradeoffs of perceptions of environmental risk)

SES 24. Nutrient management effectiveness and innovation

Seven of 27 survey responses describing critical science for EBM (all seven of which were specifically reviewing Lake Erie), and many planning documents, generally identified a need for better understanding of nutrient cycling and how the cycling dynamics relate to management actions. Lake Erie experiences greater eutrophication than the other lakes because of intensive agriculture in the watershed (Waples et al., 2008), which exacerbates natural seasonal hypoxia and affects fisheries and drinking water quality (Environment and Climate Change Canada and US EPA, 2019). Effective management strategies for nutrients were a major component of the Binational Great Lakes Water Quality Agreement (Canada and the United States of America, 2012). While extensive research over the past 50 years has helped describe the role that watershed-derived nutrients play in establishing eutrophication levels of the lakes, gaps in understanding still constrain effective management. Some of these gaps could be filled by a better evaluation of how historical management strategies have worked to reduce nutrient runoff and how these changes have affected overall nutrient cycling and lake productivity. (2019). Recent work has illustrated the need for improved modeling of nutrient transport from watersheds to the lakes to enable adaptive management strategies (Great Lakes Science Advisory Board, 2019).

Impactful EBM approaches could include institutional innovation for coordinating efforts in targeted watershed management and nutrient runoff reduction strategies. Examples of this need appeared in recent recommendations for a multi-institutional framework to coordinate planning and inter-agency cooperation and data integration to develop and employ precision nutrient conservation and stormwater optimization methods (Great Lakes Science Advisory Board, 2019; The Great Lakes and St. Lawrence Collaborative, 2019). The greater magnitude and frequency of intense storms and overland runoff associated with climate change will further emphasize the importance of effective nutrient management strategies (Environment and Climate Change Canada and US EPA, 2018a, 2019).

The following examples of cross-cutting research could improve understanding and application for nutrient management in an EBM context:

- Effectiveness of incentives for behavior change designed to reduce nutrient runoff (e.g., fertilizer taxes, social nudges on lawn maintenance)

- Cooperative development of agricultural practices that have co-benefits for farmers and the environment
- Understanding farmers' perspectives on BMPs and nutrient retention/loss, in part to inform ways to engage a wider set of farmers in nutrient management
- Incorporation of protocols and procedures into adaptive management to allow for more rapid evaluation and responses to quickly changing science
- Technologies to enhance the potential for and efficiency of phosphorus recovery and reuse
- Improved understanding of relationships between BMP implementation and dissolved reactive phosphorus mobilization, given legacy phosphorus in soils

Governance and Incentives

Survey responses perceived substantial barriers to EBM related to existing institutional structures and stakeholder buy-in (Figure 60) and developing actionable management goals was ranked among the most difficult elements of EBM to achieve (Figure 58). Calls for more effective communication and stakeholder engagement for management in the Great Lakes were ubiquitous in regional planning documents. An interviewed scientist believed, "we finally have the science" to manage, but described a need to do a better job of communicating "the why and how" to on-the-ground implementers. Studies that compare management actions in terms of their implementation costs, effectiveness, risks, and compatibility with legal restrictions and social norms are additional types of integrated social and ecological science that can inform EBM strategies.

GI 17. Tools to improve lake level management strategies

Likely due to major flooding in the Great Lakes region in 2017 and 2019, our survey showed water level management to be a salient concern. Survey respondents mentioned the importance of science to improve lake level management and flood forecasting. Water supply and control are strictly managed in the Great Lakes region. The 2008 Great Lakes Compact bans the diversion of water outside the basin with few exceptions. The International Joint Commission regulates flows from Lake Superior and Lake Ontario. Over the last decade, Great Lakes water level management has been challenged by both extreme lows and highs, and recent flooding has been particularly challenging on surrounding communities.

The recent recognition of ecosystem values of a "more natural hydrologic regime" has been integrated into management, while maintaining the goal of moderating major water level fluctuations (International Joint Commission, 2014). Climate change is expected to increase heavy precipitation and flooding in the Great Lakes (Wuebbles et al., 2019), creating a need for science to project hydrologic conditions and to generate adaptive management strategies. Integrated science is also needed to explore the social, health, and economic effects of successive flooding events (Minnesota Sea Grant, 2018). Priorities included increased and more effective stakeholder and indigenous community engagement in order to fully acknowledge and communicate flood risks (The Great Lakes and St. Lawrence Collaborative, 2019).

The following examples illustrate science to support effective lake level management to protect habitat while also managing for flood threats and climate change:

- Projection of changes in water levels and flood frequencies under anticipated near-term and long-term changes in precipitation patterns
- Effects of lake level management scenarios on the provisioning of habitat of coastal wetland environments
- Innovative methods for ensuring ecological resilience in highly managed systems under climate change by facilitating adaptive management strategies
- Socioeconomic effects of flooding and exploration of creative individual and portfolio approaches to mitigation strategies

GI 18. Shoreline resiliency planning

Survey respondents expressed a need for research and model development to predict shoreline change and sediment transport in the Great Lakes. Institutions in the Great Lakes region have begun to make resilience a major priority and have acknowledged that climate change adaptation projects should aim to increase resiliency to multiple stressors. Climate change is contributing to changing precipitation patterns and leading to increasing inundation and erosion on the shorelines of the Great Lakes.

Water levels reached historic highs in 2019 and are expected to continue as such through 2020 (US Army Corps of Engineers Detroit District, 2020a, 2020b). The establishment of the Lake Ontario Resiliency and Economic Development Initiative in 2019 committed funds to rebuild compromised shorelines in New York for long-term resilience. Building shoreline resilience, with a focus on nature-based approaches and green infrastructure, is envisioned as a collaborative effort among government and non-governmental organizations working with the shoreline communities (The Great Lakes and St. Lawrence Collaborative, 2019).

Examples of new science to support shoreline resiliency planning included:

- Effectiveness of green infrastructure and development and testing of innovative methods for stabilizing shorelines
- Ecosystem and habitat effects of shoreline hardening
- Forecasting tools for projecting erosion rates and shoreline evolution
- Vulnerability assessments of human communities to shoreline change and cost-benefit analyses to support decision-making designed to mitigate changes and ensure the continued generation of ecosystem services
- Institutional approaches (e.g., regulations, economic incentives) that enable cost-effective use of resources to address flooding and erosion
- Socioeconomic value of proactive implementation of resiliency actions
- Evaluation of the ability to maintain or adapt infrastructure under changing conditions to determine the most cost-effective long-term solutions

Conclusion

Ecosystem-based management strategies in the Great Lakes have been a part of regional objectives for decades. Early adopters recognized the key elements to success in EBM were systematic and inclusive strategies that could garner leadership commitment (Hartig et al., 1998). Our synthesis determined that these are still critical elements and the ecological and social science suggestions herein were suggested by sources within the region to improve the capacity for EBM in the Great Lakes. Much of the science suggested through our analysis will take a broad systems-level approach to achieve. Survey and interview responses suggested that the longevity of ecosystem science in the Great Lakes presents an opportunity where existing integrated ecological knowledge is poised to support improved EBM implementation. An overarching objective of the EBM needs that were described for the Great Lakes was for information and tools to enable planning for restoration and conservation for ecosystem and human community resiliency.

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APPENDIX A: METHODS

Through a partnership with the NOAA National Center for Coastal Ocean Science (NCCOS) and the Cooperative Institute for the North Atlantic Region (CINAR), we investigated present implementation status, research needs, and perceptions of ecosystem-based management (EBM) in coastal regions of the US. We were charged to perform a high-level analysis to identify research needs that, if fulfilled, would enhance the implementation of EBM strategies in coastal regions of the US.

One of the purposes of this project was to provide an update to the Regional Ecosystem Research Prospectus (2008 Prospectus; NOAA National Centers for Coastal Ocean Science 2008), a 2008 document that has helped guide regional coastal science research to address EBM and other management needs. The major objectives of science needs described in the 2008 Prospectus were to expand regional approaches and coordination and to develop models to support ecosystem-level management. We relate our results to the 2008 Prospectus to provide information on the persistence of some needs, evolution of thinking on some of the re-occurring needs, and the emergence of new science needs.

GEOGRAPHIC ORGANIZATION

Coastal management in the US is done at a variety of spatial scales. Our analysis made an effort to consider national research priorities and common concerns important to the EBM approach and the EBM science needs appropriate at the regional level. We used the nine coastal regions of the US broadly characterized by the US Exclusive Economic Zones and further delineated by NOAA's Coastal and Marine Spatial Planning program (https://www.data.gov/ocean/ocean-regional-planning-efforts). This demarcation allows for some characterization of the coasts climatologically and morphologically, but there can be dramatically different ecosystem characteristics within each region. For example, while the US West Coast is represented as a single region in this report, we acknowledge that ecosystems of the California coast are markedly different from those of the Pacific Northwest. However, on a national view, the nine regions offer a high-level spatial scale that does draw upon some similarities and connectivity of systems within each region and is the scheme used by NOAA for other purposes. The science identified in this report may be most appropriate at the sub-regional or local scales for specific systems within each region. Research design and management actions in an EBM context would be tailored for the local conditions and situations at the implementation scale of system or connected systems.

LITERATURE REVIEW

To augment our information base, we incorporated peer-reviewed research pertinent to coastal and Marine EBM. In addition to a general search on coastal or marine EBM and the use of tools at Web of Science to identify additional authors and publications, we used the snowballing technique where one article's references lead to another. We assembled foundational literature describing EBM history, philosophy, and its relationship to other management strategies. We then concentrated on literature published after 2008 to extract research directions and progress since the 2008 Prospectus. We used the five key ideas identified in our operational definition of EBM to prioritize literature describing an ecosystem approach to management and planning that expanded our literature review to other comprehensive coastal and marine planning strategies that may not have been termed EBM but promoted similar ideals and strategies (e.g., marine spatial planning, integrated coastal zone management, ecosystem-based fisheries management; Figure A1). Our searches led to a wide-ranging, though undoubtedly incomplete, assemblage of EBM-relevant information.

We identified five common intentions of the ecosystem approach: using interdisciplinary science, acknowledging trade-offs, recognizing interconnected processes, presenting actionable goals, and maintaining a healthy, productive, and resilient ecosystem. We developed the following concise operational definition of coastal EBM to guide our information gathering and formulation of issues and critical science needs.

Ecosystem-based management is an interdisciplinary approach to environmental management that considers the multitude of interconnected processes and the environmental, social, and economic tradeoffs associated with actionable goals for restoration and protection of healthy, productive, and resilient ecosystems.

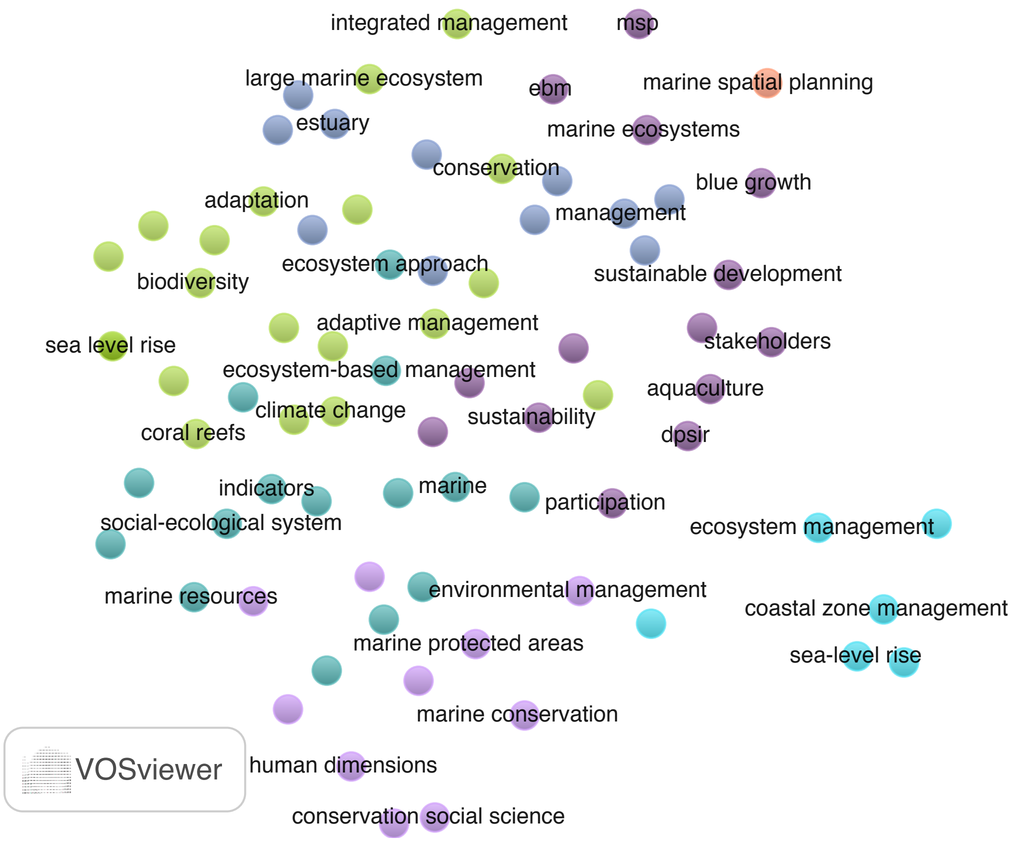

Figure A1. Sample graphical strategy used to identify and relate management concepts. This image displays an example of a keyword co-occurrence cluster analysis of the literature collection used in our process. This approach was used to enhance our conceptual understanding and was not intended to be a quantitative analysis or systematic review procedure.

Management Plan Review

We also accessed regional, state, tribe, and local coastal management plans and guidance documents published online and evaluated them with respect to how the priorities and approaches related to EBM strategies, whether or not they were presented specifically in an EBM context. This information provided a basis for understanding how the key elements of EBM were currently included in coastal management. Cursory review of comprehensive management plans, team discussions of the critical components of EBM, and experience with coastal resource management processes allowed us to identify four broad categories important for assessing the extent to which a management plan captured EBM objectives:

Motivation

We looked to identify any particular impetus for the development of the plans. This could include negative environmental conditions that spurred action, such as frequent hypoxic events or declining fish populations influencing coastal economies, as well as legal requirements, such as a Total Maximum Daily Load or governmental mandate.

Cooperation

We acknowledge that coastal ecosystems have broad stakeholders and that effective coastal management also requires broad support. We sought to determine the extent to which management plans involved various communities in prioritization and planning as well as the governmental and non-governmental partnerships contributing to the plan.

Institutional Capacity

Funding and trained personnel are a requirement for action. We regarded institutional capacity as information in plans that suggested funding resources (existing or proposed), noted any political leadership involvement, or included the commitment of cooperative management strategies and monitoring initiatives as part of implementation and review of the plan.

Scientific Research

Most plans included some acknowledgement of the existing social and ecological science and uncertainties in the ecosystem. For the purposes of this report, we were particularly interested in the reported science gaps and the planned or proposed activities for research and monitoring.

Next, we created four elements within those main categories to theorize what a complete EBM plan might include (Figure A2). We examined the planning and strategy documents for their level of inclusion of these elements within each category. Three levels were considered: no mention, non-specific use of concepts, or specific incorporation into goals or strategies. We found that major structural differences in published planning documents prevented a more systematic analysis. Instead, we used our review to better understand the extent to which EBM strategies have been documented within published plans by various coastal planning agencies and to support the science needs that emerged throughout our continuing analysis.

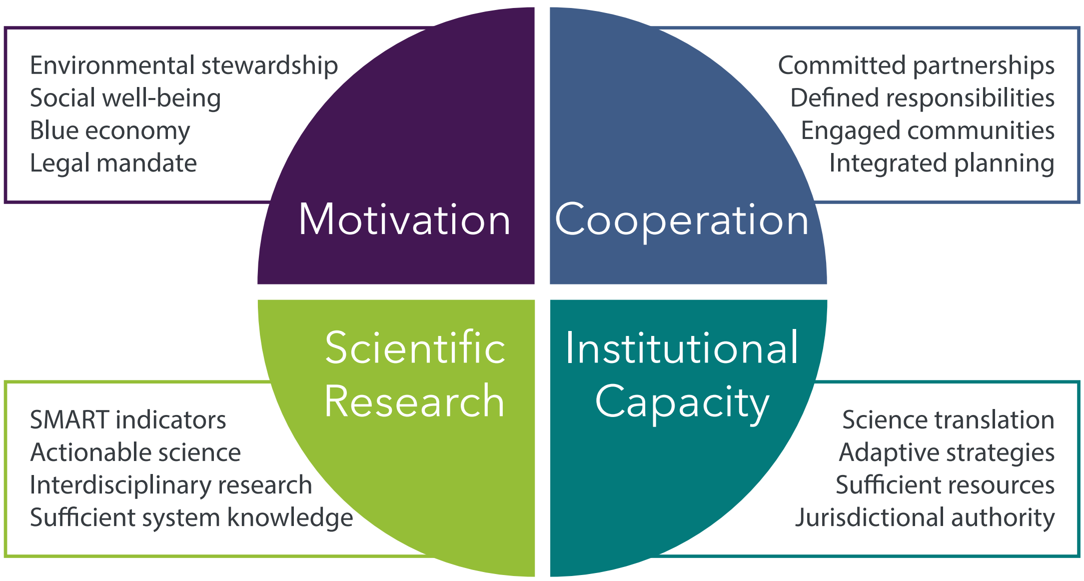

Figure A2. Categories used to examine local and regional planning and strategy documents.

Online Survey

Survey Design

We developed a cross-sectional survey (Appendix B) that was intended for a non-random audience of coastal managers, scientists, and policy makers working in the US. The survey was designed to elicit opinions and experiences with EBM, along with the major objective to collect information on perceived science gaps that, if filled, would enhance or enable local or regional EBM strategies. A pilot survey was tested with a focus group made up of individuals from our target audience, including EBM experts, and was revised based on their comments and suggestions.

The online survey (Appendix B) was IRB approved and conducted online via Survey Monkey. The survey consisted of three webpages (not including the informed consent and agreement to participate page) and response to any query was optional. Ten survey queries (SQ) were recorded with radio buttons (e.g., choose one of five levels on a scale of strongly agree to strongly disagree), six of which allowed participants to add comments via a text box. Six survey inquiries requested only an open-ended text response. The first page of the online survey included introductory questions about the participant's role in coastal management. The second page included eight inquiries specific to a location defined by the participant. Participants were provided the option to repeat the queries of the second page for up to four different locations. The final page offered five more inquiries related to the participant's general experience with EBM and their willingness to participate in follow up communications.

Survey Recruitment

We sent direct email invitations to 833 individuals identified from state and federal agencies and other non-governmental organizations (including regional partnerships, councils, and research organizations) involved with coastal ecosystem science, management, and planning. Emails included both a weblink to the survey and a weblink to a website we created to provide more information on the project with a direct link to the survey (www.coastalEBM.com; not currently in service). The invitation emails were initially sent via the Survey Monkey tools. At some point during the survey, our website was flagged and blocked by an organization's cybersecurity service. Once we learned of the issue, we were able to have the website reclassified, but may have missed some opportunities to reach participants. We switched to sending follow-up emails directly from our institutional email addresses. We also sent invitations, with the survey and website weblinks imbedded, via three community listservs: ECOLOG-L, GLIN Announce, and EBM Tools Network. We further shared a survey link via QR code on cards offered at three professional conferences. Unique weblinks were used in the email invitation generated via Survey Monkey and a generic weblink to the website was provided on the listservs. The QR code and some follow-up emails included weblinks to both the website and the generic weblink directly to the survey.

We collected survey responses from 30 August 2018 through 13 May 2019, with 355 individuals beginning the survey and 216 surveys ultimately used for analysis. Surveys with no responses past the first page and those describing locations outside of the US were omitted. The remaining surveys were included in our analysis, though a few answers may have been left blank by participants (the number of responses to a specific survey query is provided when discussed in the text). In total, the 216 final survey participants described EBM needs and opinions for 230 named coastal locations in the US.

The multiple ways we reached potential participants allowed us to reasonably approximate the number of respondents reached via the different recruitment methods. Of the 216 survey responses used for our analysis, 153 individuals used the generic weblink to access the survey and 63 users (29%) accessed the survey directly from the email sent through Survey Monkey. Based on the date the survey was accessed via the generic weblink, we estimated that approximately 20% of the surveys were related to requests via the three listservs. The remaining responses were attributed to the generic weblink and could not be tracked directly to a particular recruitment method. These participants could have accessed the survey via the QR code on contact cards, through the website, or from the weblinks provided in emails sent from the researcher's institutional email address. The website attracted 248 unique visitors during the data collection period, with the majority of those occurring during the early email recruitment time period (September-October). The exact number of people who received an invitation to participate in the survey could not be estimated, thus a response rate was not calculated. Emails may have been blocked by spam filters or forwarded to other individuals and the numbers reached via listservs and QR codes was unknown.

Survey Analysis

For Likert-type survey inquiries that were specific to a location (Appendix B; SQ 5-12), we calculated basic descriptive statistics (i.e., proportions) of responses for each region. For those inquiries that were not related to a named region or location (Appendix B; SQ 2-4 and 40-42), we calculated basic descriptive statistics for all responses.

Three survey inquiries with text responses were particularly relevant to the needs of this report (Appendix B; SQ7, SQ10, SQ42). Each of these was coded based on general ideas and themes captured in the response. We used an open coding technique to organize the text of these survey responses according to general topics and idea themes (Tables A1, A2, A3). This process allowed us to let common themes emerge from the data, rather than being defined a priori. Codes were refined and added to reflect the full set of responses. We iteratively recoded responses using a constant comparative approach, as needed, to unite themes toward a concise list of respondent ideas. For example, the SQ10 response "Sediment dynamics, storm surge modeling, and valuation of ecosystem services provided by marshes" was initially coded with the following terms: (1) sediment, (2) storm surge, (3) socioeconomics, and (4) wetlands.

After further evaluation of all responses, the second term, storm surge, was recoded to extreme events and the code storm surge was dropped. The third code, socioeconomics, was later separated into socioeconomic impacts of management actions and valuation of ecosystem services to better capture the context of the variety of responses that were initially coded more broadly. This process helped to maintain a reasonable number of codes at a level of specificity consistent with that of the range of responses. On occasion, we referenced other comments by the participant in an endeavor to fully understand the context of their responses.

Table A1. Themes and total numbers of responses coded for SQ7: Are there any other issues in [the location] that you would describe as very or extremely important? Please list. The issues listed in the leading inquiry were coastal resilience, invasive species, water quality, habitat integrity, aquaculture, human health, offshore energy, shipping, and water allocation/supply.

Code	Count	Code	Count
Acidification	4	Harmful algal blooms	6
Climate change	38	Land use	11
Communication & collaboration	6	Management strategies	3
Corals	3	Marine mammals	6
Non-extractive uses	23	Multi-use conflict	4
Development & infrastructure	9	Plastics & debris	4
Effects of development, use, & interventions	13	Pollution	17
Erosion	6	Protected species	11
Eutrophication	3	Sea ice	3
Extreme events	8	Sea level rise	17
Fisheries	43	Socioeconomics	19
Flooding	8	Species distribution and productivity	6
Freshwater-marine connections	8	Tourism & Recreation	12
Habitat restoration	2	Wetlands & Marshes	5

Table A2. Themes and total numbers of responses coded for SQ10: List the critical scientific information still needed to support or enable EBM in [the location].

Code	Count
Acidification	7
Aquaculture	4
Birds	4
Carbon	3
Climate change	41
Coral reef conservation & recovery	6
Data synthesis	10
Ecological impacts of management actions	34
Erosion	11
Extreme events	14
Fisheries	40
Food web	27
Freshwater connections	13
Green infrastructure	4
Habitat mapping	20
Habitat value & assessment	21
Harmful algal blooms	14
Human health	5
Hypoxia	16
Invasive species	5
Knowledge exchange	16
Methods to achieve EBM	27

Code	Count
Metrics & monitoring	24
Microplastics	2
Modeling & prediction	17
Noise	4
Nutrients	27
Offshore energy	4
Physical oceanography	13
Pollution source & fate	19
Protected species	6
Resilience	13
Salinity	4
Sea level rise	14
Sediment	10
Shoreline modification	5
Social vulnerability & justice	8
Social-ecological connections	24
Socioeconomic impacts of management actions	43
Species distribution & productivity	27
Use conflicts & trade-offs	27
Valuation of ecosystem services	22
Water level & flow	4
Wetlands	12

Table A3. Themes and total numbers of responses coded for SQ42: Aside from scientific information, what do you consider to be the biggest barrier to EBM implementation?

Code	Count
Communication	27
Conflicting interests	32
Coordination across agencies	26
Economic pressures	9
Existing institutional structures	50
Interdisciplinary capacity	12
Issues of scale	7
Jurisdictional boundaries	6
Lack of EBM examples	4
Lack of incentives for change	20

Code	Count
Lack of trust	11
Perceptions of EBM	14
Permitting	4
Political will	44
Resource commitment	49
Scientific uncertainty	18
Stakeholder buy-in	45
Timescales	9
Uncertainty of social impact	7

Semi-Structured Interviews

After an evaluation of survey results and with input from the advisory committee, we devised a set of IRB-approved interview questions (Figure A3) that could help us better understand certain survey responses and gain more detail on science needs and their relevance to EBM. We evaluated survey responses of individuals who expressed their willingness to participate further and had provided contact information. We selected three interview subjects from each of the nine regions for the semi-structured telephone interview. Interviewees were selected based on three main criteria: (1) Participants was thoroughly engaged in the survey, (2) Participant provided thoughtful, unique, or notable science suggestions that would benefit from elaboration, (3) The participants selected within a region each described a different location (or described the region generally) and, when possible, represented a range of work titles (scientist, resource manager, policy maker). A single researcher from our team conducted all of these interviews to maintain a reasonable level of consistency. We conducted interviews between 5 February and 8 April 2019. Interviews were not recorded to maintain privacy and increase the comfort level of participants to express their opinions openly, but extensive notes were taken and key statements were noted as quotations. It is important to acknowledge the inherent bias introduced in having the investigator take notes rather than record an interview. Interview responses referring to critical or emerging science needs were merged and coded similarly to the methods described for the online survey responses.

Telephone interview guide

1. You mentioned ____ as critical science needed to advance EBM, why did you choose this?
2. You listed ____ as an extremely important issue(s) in [the location], why did you choose this/these?
3. You previously talked about a need for ____. Is that the scientific link we should be pursuing? Why hasn't it been done yet?
4. In your experience, what key ingredient could make THE difference in achieving EBM (truly integrated management goals)?
5. Of the progress you have made in EBM, what has been most critical to success?
6. You defined ____ as the most difficult aspect of EBM to achieve, why do you think it is so difficult?
7. In your experience, what is the single-most effective strategy for encouraging EBM?
8. Describe the members of a workshop that could effectively devise a research plan that would increase EBM in [the region].
9. If you had the opportunity to have a NOAA science program or project implemented under their guidance for EBM, what would you do?

Figure A3. Interview questions list. Questions guided telephone interviews but follow-up questions and conversations were allowed to progress organically.

Informal Engagement and Reviews

We organized and chaired sessions dedicated to coastal EBM at three conferences and invited researchers and managers to present their experience and discuss regional needs to support EBM implementation. We presented preliminary survey results and national and regional analyses at these three sessions and at two other professional conferences. We invited participants and audience members to join us in informal EBM conversation after each session.

These discussions allowed us to learn more about perceptions of EBM, emerging research topics, and progress in facilitating an ecosystem approach to managing the US coasts.

We also shared drafts of the regional chapters with individuals within NOAA (e.g., Cooperative Institutes, Sea Grant) and in other agencies (e.g., universities and regional partnerships) with a request for a cursory review to assess three aspects: 1) Does the chapter appear balanced and hit the "right" high points? 2) Are there any glaring omissions? 3) Is the format approachable (e.g., any lack of clarity)? All incoming comments were considered. Reviews were generally positive and mostly focused on minor revisions for clarity or completeness. In some cases, reviewers expressed concern about the low number of survey responses (Pacific Islands and Alaska), a concern we shared. In particular, reviewers of both the US Pacific Islands and the Alaska chapters provided comments and perspectives on critical science needs that were helpful during revisions.

Regional Synthesis

We reviewed all survey and interview material for each region to identify any overarching themes in the research needs suggested by respondents. We focused on survey responses to SQ7, SQ8, SQ10, and SQ41 (Appendix B) and all interview material as a first step.

During coding, and while evaluating science needs at the regional level, we recognized several science themes that were common across regions. These national-level issues were nested to represent their interconnectedness (Figure A4) and acted as broad categories as broad categories into which we organized the specific needs and examples across regions.

Figure A4. National-level hierarchy of critical science themes

Ecosystem Science is a core theme that includes biogeochemical and physical research aimed at understanding ecological system elements and their interrelationships. *Socio-Ecological Science* is the theme that encompasses ecosystem science and research into human dimensions of EBM that aims to link human-environment interactions. The next theme is *Governance and Incentives*, which covers decision drivers, including opportunities for and constraints to EBM as influenced by institutional structures, capacity, and procedures. Finally, *Resilience Science* involves all three of the previous themes to reflect the overarching idea of integrated science to understand vulnerability, compounding impacts of change, and effects on both ecosystem and human community resilience. While we did not dedicate a section in the chapters to resilience science, we recognized the familiar theme for science to understand and achieve ecosystem resilience communicated within the vast research needs of the other categories. These categories, for the most part, are a convenience for giving structure to this report. Ultimately, EBM requires cross-cutting science and the research and tools to realize EBM will, to varying degrees, be integrated across categories.

To key in on the science needs that would enhance EBM in a particular region, we began with organizing the data by the frequency of topic codes from relevant survey responses (SQ 7, 8, 10, Appendix B) to objectively identify the range and most common topics for science investment named by respondents. We then returned to the full survey text and interview notes to consider each theme in context and capture the details from the responses. We explored responses across each survey to ensure we had a clear understanding of the meaning of individual responses. We isolated the main ideas of these responses and the science needs identified or elaborated upon with interviews in a table for each region, grouped by major themes. We added notations to the table where similar research objectives appeared in regional planning or science strategy documents. For example, once we identified a leading idea from respondents, such as connectivity between pelagic and benthic communities, we then placed it in the context of a broader research theme, in this case Ecosystem Science. The table was reviewed by multiple researchers on the project team until we reached consensus on specific topics and appropriate sub-topics and examples relevant at the local to regional scale. Each chapter was then drafted, reviewed by the research team, distributed to external reviewers, and revised.

Step-by-Step Process

Step 1 – Review EBM literature, and regional management plans and strategy documents

Step 2 – Conceptualize objectives of an online survey

Step 3 – Develop and conduct online survey

Step 4 – Analyze and code survey responses

Step 5 – Develop semi-structured interview and identify interview participants

Step 6 – Isolate topics from survey and interview responses into a table for each region

Step 7 – Pursue similarities in overarching ideas, consider how themes overlap to broad research objectives that could benefit EBM strategies in the greater region, reflect on how some of the singular research suggestions might funnel into broader themes

Step 8 – Return to the literature to identify where research and management plans corroborate or expound on ideas and add similar needs and related objectives to the table

Step 9 – Cooperatively derive specific topics that reflect the regional science needs

Step 10 – Assemble examples from survey and interview responses or subtopics of science that illustrate the main topic

Step 11 – Prepare regional summaries and distribute for internal and external review

Step 12 – Prepare national level synthesis

Step 13 – Revise and refine

CAVEATS

As a non-random sample (survey invitations were targeted and respondents self-selected), survey results are not necessarily statistically representative of the population of coastal managers, scientists, and policy makers in the US.

In reporting survey results, we provided information on the frequency of topics appearing in responses. These results were not intended to be an indicator of urgency or to be used for prioritizing research in the region. The goal of this project was to assemble a list of research needs, with specific illustrative examples, that coastal managers, scientists, and policy makers said would to support regional-level EBM.

Our survey was effective in identifying broad science needs and illustrative examples but some caution is needed in interpreting the survey results. The survey was designed so a diverse set of people could voluntarily respond and offer their current views on science needs to advance EBM, and in most regions, we obtained sufficient responses to formulate many examples to clearly illustrate the science needs. However, the survey was not a statistically-designed survey, which means one should not infer that the responses reflect a broader population of scientists, managers, and policy makers, nor are they the only critical science needs and the examples are not necessarily the most prevalent needs in a region. Our results were designed to provide critical science needs by topic, illustrated with examples, for ways to further the implementation of EBM in each region.

A full literature review of each of the subjects and science needs presented in this report was outside the scope of this project. We acknowledge that scientific advancement on some topics may not be adequately represented in the chapters. We let the online surveys, interviews, and the regional and local planning documents steer these results, and thus did not prioritize science or introduce unique research needs that did not appear in our sources. We note that our results submit the most salient science needs of the respondents self-selected to participate and that there are likely other important emerging research needs that were not identified through this process.

Appendix B: Online Survey

Introduction

You have been selected to participate in a research study being conducted by a team at the University of Maryland Center for Environmental Science. You were selected based on your role in coastal resource management. Your perspective is valuable for understanding the needs and challenges for managers in coastal marine ecosystems. It should take about 15-20 minutes to complete.

This survey seeks to help identify critical institutional and research needs to support ecosystem-based management (EBM) strategies in coastal marine areas. Results from this survey will be used to evaluate the current status of EBM and to design follow-up surveys, interviews, and workshops with resource managers. Results from this research will be used, in part, to develop guidance documents for the National Oceanic and Atmospheric Administration to identify regional research needs that could make EBM more achievable.

* 1. Please read the following and indicate your willingness to participate in this survey.

Project Title

Challenges and opportunities in coastal marine ecosystem-based management

Purpose of the Study

This research is being conducted by Amie West at the University of Maryland Center for Environmental Science. The purpose of this research project is to help identify critical institutional and research needs and opportunities to support ecosystem-based management strategies in coastal marine areas.

Procedures

This study involves an online survey consisting of inquiries such as, "List the critical scientific information that would support or enable EBM in the location(s) in which you work". The estimated time to complete the survey is approximately 15-20 minutes.

Potential Risks and Discomforts

There is no more than minimal risk from participating in this study, including potential for the loss/breach of confidentiality.

Potential Benefits

There are no direct benefits from participating in this research. This research is intended to generate new understanding of the status of ecosystem-based management in coastal marine areas.

Confidentiality

Any potential loss of confidentiality will be minimized by using the online survey's SSL encryption and anonymous settings. In addition, data will be stored on a password-protected computer. Data may be shared with researchers at the University of Maryland Center for Environmental Science directly involved with the study. If we write a report or article about this research project, your identity will be protected to the maximum extent possible.

Right to Withdraw and Questions

Your participation in this research is completely voluntary. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify. If you have questions, concerns, or complaints, or if you need to report an injury related to the research, please contact the investigator:

Amie West

146 Williams St. Solomons, MD 20688

awest@umces.edu 410-326-7226

Participant Rights

If you have questions about your rights as a research participant or wish to report a research-related injury, please contact:

University of Maryland College Park Institutional Review Board Office

1204 Marie Mount Hall College Park, MD 20742

irb@umd.edu 301-405-0678

IRB #1251112-2

By agreeing to participate, you are indicating that you are at least 18 years of age, you have read this consent form or have had it read to you, your questions have been answered to your satisfaction, and you voluntarily agree to participate in this research study. You may print a copy of this consent page for your records.

- ◯ I agree. Take me to the survey.
- ◯ I do not agree. Exit survey.

First page

Ecosystem-based management (EBM) is an interdisciplinary approach to environmental management that considers the multitude of interconnected processes and the environmental, social, and economic trade-offs associated with actionable goals for restoration and protection of healthy, productive, and resilient ecosystems.

While EBM has been broadly applied in terrestrial and marine environments, this survey is focussed specifically on coastal marine ecosystems of the United States, including the the Great Lakes.

Thank you for agreeing to participate.

2. Thinking about the definition above, is EBM a goal in your work?

- ○ Yes, and it is currently being used.
- ○ Yes, but it is not being used yet.
- ○ No

3. Which of the following best describes your work title? Answer as many as apply.

- ☐ Scientist
- ☐ Resource manager
- ☐ Policy maker
- ☐ Environmental advocate

Other (please specify)

[ ]

4. Would you describe your work as providing guidance for management decisions in coastal marine resources?

- ○ Yes
- ○ No

Would you like to tell us more about your work?

[ ]

Location 1

The following questions are about a specific location in which you work. If you work in multiple locations, you will have the opportunity to complete the same set of questions for up to four different locations.

5. Based on your experience, please select a NOAA region that would benefit from implementing or enhancing an EBM approach.

- ◯ Northeast
- ◯ Mid-Atlantic
- ◯ South Atlantic
- ◯ Caribbean
- ◯ Gulf of Mexico
- ◯ West Coast
- ◯ Pacific Islands
- ◯ Alaska and Arctic
- ◯ Great Lakes

6. Please describe a specific location within the NOAA region selected above that would benefit from implementing or enhancing an EBM approach. For example: *the western basin of Lake Erie* in the Great Lakes region, *Chesapeake Bay* in the Mid-Atlantic region, *San Fransisco Bay* on the West Coast.

[ ]

7. Rate the following environmental concerns in the location described above (**Location 1**) by their importance in the region.

	Not important or not applicable	Slightly important	Moderately important	Very important	Extremely important
Coastal resilience	◯	◯	◯	◯	◯
Invasive species	◯	◯	◯	◯	◯
Water quality	◯	◯	◯	◯	◯
Habitat integrity	◯	◯	◯	◯	◯
Aquaculture	◯	◯	◯	◯	◯
Human health	◯	◯	◯	◯	◯
Offshore energy	◯	◯	◯	◯	◯
Shipping	◯	◯	◯	◯	◯
Water allocation/supply	◯	◯	◯	◯	◯

Are there any other issues in **Location 1** that you would describe as *very* or *extremely* important? Please list.

[ ]

8. Can you think of a specific program, agency, or effort in **Location 1** that would benefit from a targeted research investment in one or more of the topics listed above? Please describe.

9. In the course of your daily work, how much influence, if any, does input from the following types of stakeholders have on your management decisions or recommendations for **Location 1**?

	Not at all influential	Slightly influential	Moderately influential	Very influential	Extremely influential
Scientists	○	○	○	○	○
Policy makers	○	○	○	○	○
Public	○	○	○	○	○
Political leaders	○	○	○	○	○
Resource managers	○	○	○	○	○
Environmental advocates	○	○	○	○	○

Comments (optional)

10. List the critical scientific information still needed to support or enable EBM in **Location 1**. For example: *seasonal variability in nutrient enrichment, biological and social economic impacts of conservation actions, food web dynamics.*

11. Describe the following regarding their influence on EBM planning and implementation in **Location 1**.

	Strongly hinders EBM	Somewhat hinders EBM	Neither hinders nor supports EBM	Somewhat supports EBM	Strongly supports EBM
Institutional structure	◯	◯	◯	◯	◯
Governance/political will	◯	◯	◯	◯	◯
Monitoring/surveying	◯	◯	◯	◯	◯
Data availability/databases	◯	◯	◯	◯	◯
Scientific understanding of ecological linkages	◯	◯	◯	◯	◯
Inter-agency communication	◯	◯	◯	◯	◯
Personnel/resource availability	◯	◯	◯	◯	◯
Economic considerations	◯	◯	◯	◯	◯
Regional infrastructure	◯	◯	◯	◯	◯
Stakeholder dynamics	◯	◯	◯	◯	◯

Are there any other influential factors supporting or hindering EBM in **Location 1**? Please describe.

12. Based on your experience with EBM in **Location 1,** how much do you agree or disagree with the following statements?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
EBM is successfully being implemented.	○	○	○	○	○
More clarity is needed in management goals and plans before fully implementing EBM.	○	○	○	○	○
More scientific understanding of the current status of ecosystems is needed before fully implementing EBM.	○	○	○	○	○
More extensive monitoring is needed before fully implementing EBM.	○	○	○	○	○
More social and/or cultural science is needed before fully implementing EBM.	○	○	○	○	○
More meaningful interaction processes among stakeholders are needed before fully implementing EBM.	○	○	○	○	○

Are there other conditions that need to be met before fully implementing EBM in **Location 1**? Please describe.

* 13. Would you like to describe another location?

○ Add second location

○ Done with locations

Last Page

40. Thinking again of the definition of EBM:

An *interdisciplinary approach* to coastal marine management that considers the multitude of *interconnected processes* and the environmental, social, and economic *trade-offs* associated with *actionable goals* for restoration and protection of *healthy, productive, and resilient* ecosystems.

Rank the aspects of EBM in order of easiest to achieve (1) to most difficult to achieve (5).
You can drag and drop or use the dropdown menu to change the order.

- Successfully implementing an interdisciplinary approach - including defining and prioritizing management goals in consideration of varying ocean uses
- Understanding interconnected processes - for example, multiple stressor impacts and mitigation
- Evaluating trade-offs - including understanding risk and uncertainty
- Developing actionable goals (i.e., SMART goals - specific, measurable, attainable, realistic, timely)
- Interpreting healthy, productive, and resilient - including identification of ecosystem indicators and targets

41. Based on your experience, in which of the locations you described previously would scientific research (physical or social) make the most difference in management strategies for the broader NOAA region? Please describe.

42. Aside from scientific information, what do you consider to be the biggest barrier to EBM implementation?

43. Your input can help support a better understanding of specific challenges and successes in EBM and help determine where research investment may make a difference. May we contact you for further insight into your coastal management experiences?

- ◯ No, thank you.
- ◯ Yes, my email address is...

44. Please enter any additional comments about this survey or EBM that you think we should know.