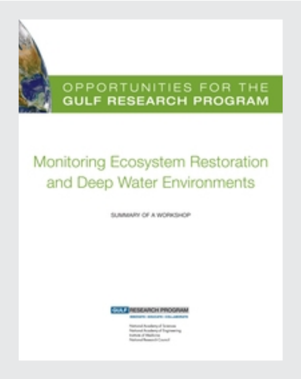

Opportunities for the Gulf Research Program: Monitoring Ecosystem Restoration and Deep Water Environments: Summary of a Workshop

DETAILS

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OPPORTUNITIES FOR THE **GULF RESEARCH PROGRAM**

Monitoring Ecosystem Restoration and Deep Water Environments

SUMMARY OF A WORKSHOP

Gulf Research Program

Kim Waddell and Steve Olson, *Rapporteurs*

GULF RESEARCH PROGRAM
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ABOUT THE GULF RESEARCH PROGRAM

In 2010 the Deepwater Horizon explosion and fire in the Gulf of Mexico caused the largest offshore oil spill in U.S. history, resulting in significant impacts on the region's environment and residents. Legal settlements with the companies held responsible led the federal government to ask the National Academy of Sciences to form and administer a 30-year program to enhance oil system safety, human health, and environmental resources in the Gulf of Mexico and other U.S. continental shelf areas where offshore oil and gas exploration and production occur or are under consideration. The new Gulf Research Program will receive $500 million to support activities using three broad approaches: research and development, education and training, and environmental monitoring.

To inform program planning, the Gulf Research Program held three Opportunity Analysis Workshops in 2014: Middle-Skilled Workforce Needs, Monitoring Ecosystem Restoration and Deep Water Environments, and Community Resilience and Health. These workshops are part of an ongoing effort to elicit input from experts, practitioners, and community members on key opportunities to translate the Program's strategic vision into activities that will benefit communities in the Gulf region and beyond. The workshops are expected to lead to the development of additional Program activities and opportunities for the research and education communities.

The Middle-Skilled Workforce Needs Opportunity Analysis workshop was delegated to the Board on Higher Education and Workforce at the National Academy of Sciences. The Gulf Research Program gratefully acknowledges the assistance that the Board on Higher Education and Workforce provided during the planning and execution of this workshop.

For more information on the Gulf Research Program and to access the additional Opportunity Analysis workshop reports, see www.nas.edu/gulf.

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This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this workshop summary:

Cortis Cooper, Chevron Corporation;
Paul Montagna, Texas A&M University, Corpus Christi; and
Alisha Renfro, National Wildlife Federation

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this summary was overseen by Linda Blum of the University of Virginia. Appointed by the National Research Council, she was responsible for making certain that an independent examination of this summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authors and the institution.

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Introduction

On September 3-4, 2014, the Gulf Research Program of the National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council (also referred to as the Program) held the second of three workshops to explore potential activities that could be supported by the Program. The themes of the three workshops—education and training, health and community resilience, and environmental monitoring—align with the Program's mandate which was identified in the legal settlement agreements that launched the Program in 2013. The environmental monitoring workshop, which was held in New Orleans, Louisiana, convened about 40 participants from the energy industry, state and federal government, academia, and nongovernmental organizations to examine two broad issues at the center of the Program's mandate regarding environmental monitoring.

This report summarizes the presentations and discussions of the workshop as a source of input to the formulation and development of the Gulf Research Program (see Box 1-1). The workshop planning committee's role was limited to planning, preparing a background paper for the meeting participants, and convening the workshop. This summary has been prepared by the workshop rapporteurs as a factual summary of what occurred at the workshop. Every effort was made to convey the words, context, and ideas used by the speakers without interpretation in this summary of workshop presentations and discussions. The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Research Council.

BOX 1-1 An Introduction to the Gulf Research Program

As part of agreements resolving criminal charges against the companies held responsible for the Deepwater Horizon oil spill—BP Exploration & Production Inc. (BP) and Transocean Deepwater Inc. (Transocean)—the National Academy of Sciences (NAS) was asked to establish a new science program focused on oil system safety, environmental resources, and human health in the Gulf of Mexico and other U.S. outer continental shelf regions that support oil and gas production. This program, known as the Gulf Research Program, is to be supported by $500 million paid by BP and Transocean between 2013 and 2018, with the funds to be expended over the 30 years between 2013 and 2043.

To guide the creation of the Gulf Research Program and propose an initial set of activities, the NAS appointed an Advisory Group of 25 volunteers with extensive expertise and familiarity with the region. The Advisory Group met to discuss the charge established by the settlement agreements, held public meetings to gather input from individuals and organizations in the Gulf region, built relationships with other organizations, and identified needs that align with the Program's assigned mandate. It also articulated a vision and identified both short-term and long-term opportunities for the Program.

The settlement agreements directed the Program to have activities in three broad categories: education and training, environmental monitoring, and research and development. The first workshop in Tampa focused on the first of these three areas. This workshop, held in New Orleans, targeted environmental monitoring, and the final workshop, also hosted in New Orleans, explored community resilience and health.[a] All three workshops were designed to contribute potential opportunities to the strategic vision established by the Advisory Group.

The 30-year duration of the Program gives it an opportunity to support short-term, medium-term, and long-term projects. Furthermore, projects at different time scales can interact with each other, producing richer results than would otherwise be the case. In addition, the Program has an opportunity to create synergies by bringing together people from different sectors and workforce areas.

[a] These workshop summaries will all be available on the National Academies Press website (http://www.nap.edu).

These participants were invited based on, in part, for their expertise on the issues and willingness to share their perspectives and insights in a public forum. The workshop speakers and participants were invited as the basis for how the workshop approached the following two issues:

1. How observations and monitoring can be used to restore and sustain the services provided by Gulf ecosystems, and
2. How observations and monitoring can be used to better understand the deep ocean and its connectivity to the coast.

Through panel discussions and breakout sessions, workshop participants identified the following:

- monitoring opportunities within these two foci, and technological and methodological innovations that could help address them,
- monitoring and observation opportunities uniquely suited to the Program's 30-year duration, and
- opportunities for partnerships and leveraging of resources

ORGANIZATION OF THE WORKSHOP SUMMARY

Chapter 1 provides an introduction to the Gulf Research Program (Box 1-1), a brief definition of environmental monitoring, and the planning committee's rationale for the workshop themes. Chapter 2 explores some of the broader issues relevant to the overarching challenge of environmental monitoring for a large complex ecosystem like the Gulf of Mexico. Chapters 3 and 4 highlight the two areas of focus for the workshop, with discussions on monitoring to support environmental restoration (3) and monitoring that advances our understanding of the deep Gulf (4). Chapter 5 provides a synopsis of the key ideas and opportunities identified during the workshop that will inform the Gulf Research Program moving forward.

ENVIRONMENTAL MONITORING AND THE GULF RESEARCH PROGRAM

The Gulf Research Program has defined environmental monitoring as "a continuing program of measurement, analysis, and synthesis to identify and quantify ecosystem conditions and trends to provide a technical basis for decision making" (NRC, 2014a). Environmental monitoring information can be used to increase basic understanding, identify emerging problems and long-term trends, inform restoration projects, prioritize use of resources, and provide information to guide policy and management. For rapidly changing regions like the Gulf of Mexico, monitoring efforts also can yield reference data that flag emerging environmental and health concerns and provide a baseline for future disasters (NRC, 2014a). Donald Boesch, President and Professor with the Center for Environmental Science at the University of Maryland, provided some context for the workshop and highlighted the issues and challenges surrounding environmental monitoring in the Gulf of Mexico. During the 30-year duration of the Gulf Research Program, coastal populations are expected to continue to grow, with increasing demands on coastal and marine goods and services. In addition, the Gulf and other coastal regions likely will face other significant environmental challenges, including climate change, sea-level rise, coastal subsidence, and the possibility of future oil spills (NOAA, 2012). These challenges will call for new tools and approaches in order to understand the extent of these associated risks and damages. Ideally, effective environmental monitoring will provide a strong foundation of data and information for scientists and managers alike to use before a challenge arises, Boesch noted.

WORKSHOP FOCUS AREAS

Environmental Monitoring to Enhance Restoration of Gulf Ecosystems

Boesch also provided the rationale for the workshop focus areas. Environmental monitoring in the Gulf of Mexico is a diverse and fragmented enterprise due in part to the numerous national, state, and county jurisdictions, and due to the fact that the monitoring efforts in and around the Gulf are conducted for a variety of reasons, including socioeconomic, geologic, physical, chemical, biological, and ecological purposes. However, the scale of the *Deepwater Horizon* oil spill highlighted the need for a regional environmental monitoring network that, for example, could have provided baseline data on a wide variety of vulnerable or affected resources (Green et al., 2014). Baseline data will be an important component for the extensive environmental restoration activities being undertaken and planned in the Gulf of Mexico if for no other reason, to provide a starting condition by which restoration success could be quantified. Baseline monitoring data can also facilitate understanding of expected outcomes without management decisions or restoration projects based on current trajectories. Changes in this complex system due to natural and anthropogenic drivers are likely unavoidable and weighing management decisions against future scenarios without management action will allow for better understanding of expected short-term and long-term outcomes and tradeoffs from management decisions. Finally, monitoring and observational data are fundamental to assessing ecosystem functions, processes, and changes over time, especially in dynamic ecosystems such as those found in the Gulf of Mexico (NRC, 2013).

One way to evaluate the outcomes of management and restoration is through quantification of the ecosystem services provided (NRC, 2013). Scientists who study ecosystem structure and functions have made significant advances in the past decade in modeling the impacts of land use, coastal development, and natural resource management decisions on a variety of ecosystem processes. As advances in spatially explicit modeling have been integrated into the efforts, researchers have developed the ability to map ecosystem services and their flows to various communities (Kareiva et al., 2011).

Despite these advances, understanding of how coastal and marine ecosystems function and react to both chronic and episodic stressors remains limited (Luisetti et al., 2014). A major limitation of knowledge is related to how ecosystem functions contribute to human well-being (Burkhard et al., 2013). The identification, quantification, and eventual valuation of ecosystem services are challenged by the need to better understand socio-ecological complexity and by a suite of questions relevant to ecosystem service flow. For example, who are the beneficiaries? Where do they live? What is the scale of the services provided? How does the management of these services/benefits influence their sustainability? Addressing these questions requires the integration of knowledge from numerous disciplines (Luisetti et al., 2014).

Increasing numbers of researchers over the past decade have been collaborating to develop modeling and mapping approaches aimed at understanding the demands and flows of ecosystem services on different spatial and temporal scales (Nelson et al., 2009; Burkhard et al., 2013). Insights into ecosystem processes are providing greater understanding of the potential supply of ecosystem services. This knowledge then can be combined with the information and data collected by economists and other social scientists who examine the demand for services and how they are connected (NRC, 2005; Nelson et al., 2009). Tools and methodologies used in observation and monitoring—such as geographic information systems, remote sensing, and thematic mapping—are also being applied in linking supply with demand for ecosystem services (Troy and Wilson, 2006).

The communities of researchers involved in expanding understanding of ecosystem services are making significant progress. With the current level of investment and research under way in the Gulf of Mexico, there is a great opportunity to advance understanding of ecosystems through monitoring and the development of ecosystem service models. Together, these efforts can be applied to support adaptive management and restoration efforts in the Gulf of Mexico, and to science, policy, and practical decision making.

Monitoring to Better Understand the Deep Gulf of Mexico

The deep Gulf of Mexico (defined here as depths greater than roughly 200 meters, much of which is beyond the continental shelf) is a vast, remote, and hostile environment that has been challenging and expensive to monitor relative to shallower waters and the coast.[1] However, an increasing proportion of the Gulf's new offshore energy exploration and production is taking place in waters deeper than 200 meters. In fact, much of it occurs in waters deeper than 1,500 meters, which has accelerated the need to understand more about deep Gulf ecosystems, both to protect their living resources and to help anticipate and mitigate the impacts from deepwater development activities. The 1500m depth of the Macondo well blowout—that led to the Deepwater Horizon drilling rig explosion and spill—brought a great deal of attention to the deep Gulf, highlighting the gaps in knowledge for understanding the impacts of a large release of hydrocarbons in this region of the Gulf. These gaps include the ability to predict how the region's physical processes would interact with the oil and dispersants—where the oil would disperse and how might the subsea application of dispersants impact the trajectory and fate of the oil.

The vastness and remoteness of the deep Gulf pose great logistical challenges for monitoring. Additional technological and methodological advances would be quite useful for stakeholders involved in monitoring and managing resources in this part of the Gulf. Practicality and cost-effectiveness are essential factors in such considerations (Green et al. 2014).

[1]Much more detail regarding the deep Gulf of Mexico can be found in Chapter 5 in the 2013 National Research Council report "*An Ecosystem Services Approach to Assessing the Impacts of the Deepwater Horizon Oil Spill in the Gulf of Mexico.*" National Academies Press. Washington, DC.

2

Environmental Monitoring: Lessons Learned, Needs and Opportunities in the Gulf of Mexico

BOX 2-1 Important Points Made by the Speakers

- Develop a set of questions that, if answered, could drive the design of a Gulf monitoring effort.
- A virtual infrastructure for data management, information, and published documents could help guide response and restoration activities throughout the Gulf of Mexico.
- Job training and the long-term involvement of the residents of affected areas can influence the success of monitoring and restoration activities.

Several presentations during the workshop explored broader issues relevant to the overarching challenge of environmental monitoring for a large complex ecosystem like the Gulf of Mexico. One presentation highlighted a plan that addresses the broad range of needs and expectations by stakeholders for environmental monitoring programs in the Gulf Region. Two presentations identified and discussed critical infrastructure components of monitoring networks, including work force development, and data integration and management. Another presentation recapped the lessons and insights from a program that directed 30 years of monitoring in the Northern Gulf. Despite its multiple decades of contributing to scientific understanding, the program's future is in doubt due to a lack of funding, which highlights the most persistent challenge for all long-term observational programs—sustained support. One of the keynote presentations detailed the approach and strategy used to develop and sustain a 10-year continental-scale observing and monitoring network known as NEON, providing details of what might be needed in designing a regional monitoring network for the coastal and offshore regions of the Gulf.

ENVIRONMENTAL MONITORING: THE NATIONAL ECOLOGICAL OBSERVATORY NETWORK

The millions of people living in Gulf Coast communities will continue to face substantial threats in the future, said Russ Lea, chief executive officer for the National Ecological Observatory Network (NEON). The rise in sea surface temperatures will create the potential for more intense hurricanes; sea level rise will create an elevated risk of erosion, storm surge, and saltwater intrusion; land areas are subsiding; and coastal inland and water temperatures are expected to rise.

The science studying these changes involves identifying multiple environmental stressors and complex interactions, said Lea. NEON was designed to enable understanding of these stressors and interactions. NEON was based on the concept that ecologists needed a distributed but integrated complex of facilities that would enable them to answer "grand challenge" questions in their field (NRC, 2001). NEON provides the infrastructure to support research, education, and environmental management in the areas of biodiversity, biogeochemical cycles, climate change, ecohydrology, infectious diseases, invasive species, and land use on a continental scale (NRC, 2003). It is divided into 20 ecoregions across the continental United States, including Alaska, Hawaii, and Puerto Rico. Across these regions facility sites are categorized into three types: sites located in unmanaged wildland conditions, relocatable sites that are representative of human land management effects on ecosystems, and fresh water aquatic sites to measure changes in aquatic systems over time. However, NEON does not have facilities on the coast because a proposed parallel program that exclusively targeted coastal sites was planned but did not get funded.

NEON is using an integrated sampling strategy across regions and biological domains. For example, its biological sampling includes plant biodiversity, plant biomass and chemical composition, leaf area, plant phenology, birds, ground beetles, mosquitoes, small mammals, infectious diseases, biogeochemistry, and soil microbes. Aquatic sampling, atmospheric measurements, soil measurements, and airborne observations are equally wide ranging. NEON is "trying to take societal benefit areas and work backwards through policy, through environmental indicators, through tools for collaboration, to how do you produce the data in the first place," said Lea.

As a specific example, Lea discussed policy for coastal adaptation (NRC, 2014b). Dunes and berms, tidal flats, wetlands, and forests near the coasts all provide essential ecosystem services, and all of these ecosystems are affected by public policies at the sectoral, regional, or national levels that address societal needs. These policies, which may be in the areas of risk management, vulnerability assessment, resource management, climate adaptation, education, or other areas, form a direct link between ecosystem services and policies designed to handle risk and produce societal benefits.

Several key tools can inform these policies, Lea observed. For example, a computing infrastructure can ingest data, run models, visualize, and share information. Models need credible, high-quality, and long-term data, and these data can come from many sources, including the biosphere, the atmosphere, the lithosphere, the hydrosphere, and social spheres. Measurement traceability, observatory interoperability, and socio-environmental integration to enable linkage to societal benefits are all important features of these data, Lea said. The data also need to be freely accessible in a common database (PCAST, 2011; NSTC, 2014). The advantage of long-term programs like NEON, said Lea, is that models and data can be developed over time, with both hindcasting and forecasting, to develop greater confidence in those models.

Lea also discussed the roles of marine laboratories and biological field stations, citing a recent National Research Council report on the subject (NRC, 2014c). This infrastructure is well distributed across the United States and has generated valuable long-term historical data records, but these facilities are not necessarily integrated with other research resources, and they often have generated heterogeneous forms of data over time. Nevertheless, they are "a rich source of information," especially if the information were readily available.

Given the needs that exist, what are the pathways to develop the appropriate indicators, models, cyberinfrastructure, tools, and data, Lea asked. He urged that a set of questions be developed to drive requirements. These requirements then would lead to a design, with subsystem designs leading to implementation. This decomposition process would be followed by integration and testing from the subsystem level to system verification and commissioning—"you learn this in engineering 101," said Lea. NEON was developed the same way, starting with grand challenge questions and developing the systems and subsystems needed to answer those questions.

In response to a question about how NEON can adapt its research program to new problems, Lea noted that technologies will be refreshed every five to eight years to take advantage of new capabilities. Also, new questions will drive the science programs within federal agencies and scientific publications, which in turn will drive changes in NEON.

In addition, Lea noted that NEON will be working with large data companies to store and make its data and metadata accessible, and these companies will be interested in using those data to leverage an expansion of their user communities. For example, a climate corporation might use proprietary algorithms with NEON data to drive a better understanding of climate as it affects farming and the use of pesticides and fertilizers.

A PLAN FROM THE GULF OF MEXICO COASTAL OCEAN OBSERVING SYSTEM

The Gulf of Mexico Coastal Ocean Observing System (GCOOS) is part of a larger Global Ocean Observing System that is more than a decade old, noted Landry Bernard, GCOOS's associate executive director. Collectively, these systems are collaborations of public, private and academic sector partners that use observations, modelling and analysis of marine and ocean variables to support operational ocean services. As the Gulf Coast's ocean observing system, GCOOS has five themes:

- Public health and safety
- Healthy ecosystems and water quality
- Mitigation of effects of coastal hazards
- Safe and efficient marine operations
- Long-term ocean variability and changes

The system acquires data from a wide variety of sources and makes those data available through a portal and in the form of various data products to meet both public and private needs.

Five years ago, NOAA decided that it wanted GCOOS and other regions under the United States' Integrated Ocean Observing System to develop a monitoring plan. Based partly on the results of numerous stakeholder workshops over a ten year period, GCOOS identified common stakeholder priorities and developed a build-out plan with the following tools and applications:

- Surface currents and waves network
- Fixed mooring network
- Autonomous meteorological measurement network
- Glider and autonomous underwater vehicle network
- Satellite observations and products
- Aircraft observations
- Bathymetry and topography mapping network
- Water level network
- Enhanced Physical Oceanographic Real-Time System
- Outreach and education
- Harmful Algal Bloom Integrated Observing System
- Ecosystem monitoring
- Water quality and beach quality monitoring
- Hypoxia monitoring
- Monitoring of river discharge
- Physical modeling
- Ecosystem modeling
- Data management and communications system
- Research input into new technology development

These new tools and applications build on the existing systems and capabilities in the Gulf, including those funded by the federal government and the states, Bernard said. Also, as with the existing GCOOS program, data management remains a prominent issue with these 19 elements. For example, parameters, quality control, and the generation and use of metadata all have been factored into the development of the build-out plan.

The build-out plan contributes to several common themes in the 2012 Resources and Ecosystems Sustainability, Tourism Opportunities, and Revived Economy of the Gulf Coast Act (known as the RESTORE Act), Bernard noted, including:

- Restoration and protection of fish, wildlife, and natural resources
- Restoration and protection of marine and coastal resources, including barrier islands, beaches, and wetlands
- Restoration and protection of ecosystems
- Observing and monitoring
- Restoration and protection of the economy, sustainable development, and sustainable technology

Bernard focused specifically on the monitoring components of the build-out plan. Restoration projects have a wide variety of environmental monitoring needs. As examples, he listed satellite imagery, radar for coastal current, sidescan sonic imagery, multibeam bathymetry, aircraft and drone camera imagery, autonomous underwater vehicle camera and video imagery, and sediment profiling. Funding these technologies requires that the total expense be divided among the Gulf States and other partners, he said. It also will require deciding among technologies—for example, buoys versus gliders.

As particular opportunities for long-term monitoring, Bernard listed several technologies:

- Use of the GCOOS-Regional Association's Gulf Glider Task Team and implementation of a Gulf Glider Network
- Implementation of a high-frequency radar network for Gulf coastal currents
- Augmentation of existing moorings and addition of new moorings with real-time sensors
- Implementation of a passive acoustics monitoring network
- Implementation of a marine biodiversity observing network
- Expanded data management and communications

He also listed a variety of recommendations for modeling, which he noted goes hand-in-hand with monitoring:

- Adapt the Gulf of Mexico Research Initiative's Deep-C Consortium's graphical map interface to allow interactive comparisons of multiple Gulf ocean circulation models simultaneously
- Support activities to further ecosystem modeling
- Prepare data sets needed by modelers
- Support the dissemination of model outputs
- Support the production of integrated satellite and other data products

Achieving these advances will require workforce development. Information analysts and modelers are needed to synthesize disparate data sets and develop useful information products for decision makers, Bernard said. In addition, "we need data providers who can use ocean data to create and provide data products. We also need marine technology innovators who can develop devices that operate in real time, resist biofouling, and are more sensitive, among other desired attributes."

COMMUNITY ENGAGEMENT AND ENVIRONMENTAL MONITORING

"Environment monitoring points to jobs, and for us that's key," said Patrick Barnes, president of the environmental engineering and scientific consulting firm BFA Environmental. The environmental monitoring needed for coastal monitoring can generate jobs for the communities at risk from coast change, and BFA tries to incorporate environmental job training into everything that it does. "We don't go into an area and do monitoring just for the sake of monitoring; we want to do it in a way that includes the communities. We don't think that an area is really restored unless the community is fully engaged. And true engagement is not just about education; it's also about training and long-term involvement of the residents of an area that's impacted."

Barnes described a recent trip to Costa Rica where everyone he met, no matter their occupation, was engaged with the environment. The environmental challenges in the Gulf provide an opportunity to build a similar kind of engagement, he said. "We can integrate into our system, even at the elementary level but certainly at the middle and high school levels, a curriculum that builds that sort of ownership for the students so that they are aware of the value of the coast on every level." Then, when a storm occurs, "they have an interest in being there to help fill the needs on those projects."

In 2006, Barnes' firm started a job training program called Limitless Vistas that has trained more than 400 at-risk youth in Louisiana as environmental technicians. Program graduates, many who were mostly unemployed or underemployed at the beginning of their training, developed the skills they needed to do monitoring work. Given the success of the program, Barnes called for a larger-scale effort and a more direct linkage between industry and job training.

Job training and environmental monitoring both provide ways of engaging with communities across political jurisdictions and scaling up small projects to larger ones, Barnes concluded. They also provide ways of learning what communities expect and can contribute when a disaster strikes and restoration activities are needed.

DATA MANAGEMENT FOR ENVIRONMENTAL MONITORING

The day after the *Deepwater Horizon* drilling platform exploded, Russ Beard, director of the National Coastal Data Development Center, received a phone call asking him to assemble a joint analysis group to work on the assimilation, integration, and visualization of all the data being gathered by NOAA observing systems and other sources on the resulting oil spill. The group's tasks included overseeing the calibration, validation, quality control, and generation of metadata for the incoming data streams. The data then would be used by agency managers to protect living marine resources and human health. In addition, the data would be archived in data centers for use by the research community and other interested groups.

This experience revealed several flaws in the existing system, Beard said. First, there was a failure to establish a consistent and coherent policy throughout the data management process. Second, there was no clear chain of command to drive the collection requirements. Third, the science advisory panels were not always able to provide guidance on vessel sampling locations or protocols. Fourth, data-sharing protocols and public access agreements either were not in place or were poorly understood by industry, academia, and government. Finally, the absence of an existing virtual infrastructure added latency to meeting data requirements for response and restoration.

The challenge facing data managers today is how to deal with petabytes of information derived from the Gulf of Mexico ecosystem, Beard said. Data sources range across oil and gas production, habitats, human health, community resilience, living marine resources, stock assessments, socioeconomic impacts, recreational fishing, and environmental indicators. To deal with this huge amount of information, Beard recommended that a virtual infrastructure for data management, information, and published documents be established for all Gulf of Mexico response and restoration activities. Key components of this infrastructure would include funding entities; data providers; data discovery, access, and visualization services; supportive metadata; online metadata catalogs; end users; and institutional repositories for data and documents.

Beard particularly emphasized the generation and use of metadata to do filtered harvests and federated searches. Data integrators could access data from providers, who in turn could draw data from existing national institutional repositories. The results of this data integration could be provided to users through a portal or dashboard.

Such a system would have both short-term and long-term benefits. Data providers either already possess or can easily establish Web Accessible Folders or Catalog Services for the Web that make their data accessible. Most providers already develop and provide acceptable levels of metadata. Establishing a public Gulf of Mexico Geoportal Server, which Beard labeled as one option, would be inexpensive; data could continue to be accessed from authoritative sources via existing infrastructure and databases; and data would be free to users. Finally, the originators of the data would continue to receive citations even as users are able to discover data they do not know about or would have difficulty finding with current tools.

MONITORING THE HYPOXIC ZONE OF THE GULF

Nancy Rabalais, executive director and professor of the Louisiana Universities Marine Consortium, described her three decades of experience studying the dynamics of the large hypoxic region in the Gulf of Mexico. An area of low oxygen has been forming every summer since Rabalais began monitoring the area in 1985. Gradually the monitoring effort has expanded, except for a few years in which data were not collected because of a lack of funding. Her monitoring and research effort also has taken advantage of ancillary data collected by the U.S. Army Corps of Engineers and the U.S. Geological Survey.

Rabalais commented on the importance of "knowing what your question is." With the Gulf hypoxic zone, the initial question was how big it is and where it is. But over time the questions being asked have multiplied, and the collection of data has allowed Rabalais and her colleagues to test hypotheses with their observations. Models have been developed and are now used to explore the properties of the hypoxic zone and better understand the dynamics of the system, with directed experimental work done to refine causative models. Models even incorporate coupled systems that examine the economic costs and benefits of different agricultural practices. "We have come a long ways in 30 years," Rabalais said.

She also pointed out that technologies have changed substantially over 30 years and will continue to change. Some data are collected from ships, some from underwater cables, and some from instruments mounted on offshore platforms. Changing instrumentation poses challenges to data continuity, "but you have to have some kind of focus to start with or you are never going to get anywhere," she said.

In 2009 a group of stakeholders put together a hypoxia monitoring plan that spells out the monitoring to be done and the research to be pursued. The plan reflects both scientific needs and funding realities. It also was coordinated with other plans to foster cooperation among groups and a combined effort. However, continued funding difficulties could threaten a valuable source of information. "What's at risk is a 30-year database," she said.

OBSERVATIONS OF THE BREAKOUT GROUPS

At the end of each day during the workshop, participants broke into four breakout groups to discuss environmental monitoring opportunities with a focus on the two major areas of interest—ecosystem restoration and the deep Gulf. Some of the main points raised by the breakout groups were more broad and relevant to the larger challenge of environmental monitoring in the Gulf; they are summarized below. These observations should not be seen as the conclusions of the workshop participants as a whole. Nor are they activities that the workshop participants thought should be pursued by the Gulf Research Program. Rather, they are opportunities related to environmental monitoring and related activities, with which the Program could be involved as it develops in future years.

Socioeconomic Considerations: A Synopsis of the Discussions

- One of the more significant challenges faced by those interested in and responsible for managing and protecting coastal and marine resources is to better refine our understanding of the linkages between ecosystem dynamics and the social benefits associated with them. While both the social science and marine science communities have developed indicator systems to better assess change, the degree to which such efforts have been linked has been surprisingly limited (Bowen and Riley, 2003), hence the interest in advancing the integration of socioeconomic considerations into environmental monitoring efforts and evaluation.Monitor socioeconomic conditions, including community metrics.
- Include socioeconomic benefits in models, with links to physical and biological parameters.

Information Infrastructure

- Create a Gulf-wide "network of networks" through coordination of existing programs and data.
- Build a regional long-term reference network to allow tracking of environmental changes.
- Foster a distributed data system, including use of crowd-sourcing, big data, and citizen science.
- Set up an open standard for a common information-sharing framework.
- Make use of Natural Resource Damage Assessment data and other legacy studies.

3

Monitoring to Support Environmental Restoration

BOX 3-1 Important Points Made by the Speakers

- While difficult to quantify, valuation of coastal ecosystem services could aid decision making by policymakers and local communities.
- A comprehensive inventory of habitats could be linked with the ecosystem services each provides to yield a consistent valuation of those habitats and services.
- Efforts to monitor, measure, or predict ecosystem services must consider social and economic parameters.
- Industry supports real-time ocean observing over extended periods of time that included not only physical oceanography but biological, chemical, and ecological monitoring programs incorporated into fixed and autonomous ocean observing platforms.
- A conceptual model that encompasses the entire suite of restoration activities could reveal missing data and priority areas that need to be addressed.
- Industry has many reasons to support long-term environmental monitoring and many ways in which it can help do so.

There were two areas of focus for the workshop, and the first full day of discussion at the workshop was dedicated to topics around the approaches, information, and support that environmental monitoring might provide with the rapidly expanding investments in environmental restoration in the Gulf of Mexico. The funds behind these investments stem from the legal settlements and legislation associated with the *DWH* oil spill and already exceed $3 billion, and this figure is expected to grow with future settlements.

There are a suite of methodological tools available to provide decision support for restoration planners and resource managers alike. They include ecosystem service valuation, ecosystem models, and trade-off analyses (Ocean Research Advisory Panel, 2013). Coastal populations in the Gulf of Mexico and their economic activities depend on many of the services provided by coastal and marine ecosystems, such as storm surge mitigation, enhanced water quality and fisheries production (Barbier, 2011). So as restoration planners are considering different restoration projects across the region, a focus on restoration efforts that integrate an ecosystem service approach (identifying services and prioritizing them based on their use and tradeoffs for the region's communities) could prove useful as well as responsive to the needs and expectations of the region's stakeholders.

VALUING ECOSYSTEM SERVICES FOR COASTAL PROTECTION AND RESTORATION

Considerable progress has been made in quantifying and valuing some of the key ecosystem goods and services provided by coastal habitats, but fundamental challenges remain, said Edward Barbier, John S. Bugas Professor of Economics in the Department of Economics and Finance at the University of Wyoming. As Worm et al. (2006) have pointed out, the loss of coastal and estuarine ecosystems has affected three critical ecosystem services studied in Europe, North America, and Australia since 1950. The number of viable fisheries has declined by 33 percent over the long term. The provision of nursery habitats such as oyster reefs, seagrass beds, and wetlands has declined by 69 percent. And filtering and detoxification services provided by suspension feeders, submerged vegetation, and wetlands have declined by 63 percent. In addition, the loss of coastal wetlands and their vegetation has affected these systems' ability to protect against shore erosion, coastal flooding and storm events; declining water quality may increase harmful algal blooms, fish kills, shellfish and beach closures, and oxygen depletion; and loss of biodiversity has been linked to biological invasion and vice versa. These are the types of services that need to be assessed when considering the tradeoffs associated with coastal development, Barbier said.

However, it remains difficult to quantify and value the benefits of such services. As the NRC Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems has noted, "the fundamental challenge of valuing ecosystem services lies in providing an explicit description and adequate assessment of the links between the structure and functions of natural systems, the benefits (i.e., goods and services) derived by humanity, and their subsequent values" (NRC, 2005). Except for some raw materials and food and fish harvests, very few ecosystem goods and services are marketed, which means they have to be valued explicitly through non-market valuation methods. In particular, the greatest challenge is in valuing the ecosystem services provided by regulatory and habitat functions. These ecosystem functions benefit human beings largely without any additional input from people. Examples include coastal storm protection, breeding and nursery habitat, nutrient cycling, erosion control, water purification, and carbon sequestration.

Barbier presented two case studies of how these kinds of services can be valued. The first involves storm protection by marshes in southeast Louisiana. The 2012 Louisiana Coastal Master Plan proposes to build 545 to 859 square miles of new land, much of it restored marsh, over the next 50 years to provide storm protection and other ecosystem benefits. Field studies indicate that coastal marsh vegetation significantly impacts wave attenuation, as measured by reductions in wave height per unit distance across a wetland. By combining hydrodynamic analysis of simulated hurricane storm surges and economic valuation of expected property damages, Barbier et al. (2013) showed that the presence of coastal marshes and their vegetation has a demonstrable effect on reducing storm surge levels and generates significant value in terms of protecting property in southeast Louisiana. A 0.1 increase in wetland continuity per 6-km segment reduces property damages for the average affected area in southeast Louisiana by $600,000 to $800,000, and a 0.001 increase in vegetation roughness decreases damages by $140,000 to $260,000. This is the equivalent of saving three to five and one to two properties per storm for the average affected area, respectively. Though other studies have produced different results, depending largely on the questions being asked and the assumptions that are made, these results suggest that wetland restoration could reduce the future vulnerability of the coast to periodic hurricane storm surges and decrease the risk of substantial flood damages to residential property, Barbier said. Better information is needed from hurricane and other tropical storm surge models to improve estimates of the distribution of expected coastal flood damages, he added, along with replication of these analyses for other locations and coastal habitats.

Barbier's second case study involved an approach used for oils spills and wetland compensation in lieu of restoration. Since the 1990 Oil Pollution Act, parties releasing oil into the environment are liable for the cost of cleaning up those releases and monetary compensation for damages to natural resources caused by the releases. The U.S National Oceanographic and Atmospheric Administration (NOAA) is responsible for assessing the effects of any offshore spill through a Natural Resource Damage Assessment (NRDA). This NRDA relies less on valuation than on habitat equivalency analysis (HEA), especially for damaged coastal wetlands. The underlying concept behind HEA is to compensate the public for losses of habitat resources through habitat replacement projects that provide additional resources of the same type. Three steps are involved in doing this analysis. The interim losses in natural resource services arising from damages to a coastal and marine resource are quantified. The scale of compensatory restoration required to offset these service losses is estimated and compensation is sought from the responsible party for the present-value monetary costs of the compensatory restoration project. By comparing services to services, valuation is not necessary.

This approach has both pros and cons, Barbier noted. Restoration is emphasized from the beginning of the NRDA, and protracted and costly litigation is often avoided. It also ensures that enough money is collected to implement complementary restoration. However, this approach assumes a preference for compensation with the same services that were damaged; it assumes a fixed proportion of habitat services to habitat value; and it assumes a constant real value of services over time. In addition, the baseline may vary, and compensation may have effects on the overall aggregate supply of and demand for some services.

Coastal wetland restoration and compensatory mitigation will feature prominently in Louisiana and other coastal states, Barbier said in conclusion. Developing methods of assessing natural resource damages, such as the effects of oil spills on coastal wetlands, while reducing costly litigation and expediting funding for restoration, is an important objective. But there also needs to be much more consideration of the long-term ecological establishment of wetland structure and functions and of the economic benefits derived from the resulting goods and services, he said. A case-by-case approach is not helpful in the event of long-term and large-scale damages.

Barbier also noted that progress in valuing key goods and services, provided by coastal ecosystems, requires interdisciplinary collaboration to link changes in ecosystem structure and function to the production of key benefits to humans. Valuation can identify tradeoffs, including the costs and benefits of various coastal management options, and contribute to assessing management effectiveness. If employed properly, valuing coastal ecosystem goods and services will aid decision making by policymakers and local communities with respect to the use and conservation of various coastal systems. However, more studies are needed that value a wider range of coastal ecosystem services in more locations and over different periods of time

RESTORING OYSTER REEFS: PERFORMANCE, BENEFITS AND TRADEOFFS

As a specific example of the link between monitoring and ecosystem services, Christine Shepard, director of science for The Nature Conservancy's Gulf of Mexico Program, observed that the Conservancy has been focusing on oyster projects to create shorelines, break waters, or reefs for shoreline restoration. As a result, monitoring has been a major component for the Conservancy in considering its restoration projects along the Gulf Coast. In particular, as these projects increase in size, the Conservancy needs to know how their benefits scale with project size.

The Conservancy has developed a set of questions to inform its monitoring activities. The first question involves the relationship between reef design type and performance. Many projects have been under way for a long time and have not been monitored. "Before we invest huge sums of money in these massive projects, we feel it's important to look back at the historical performance of these projects," said Shepard. The ecosystem services provided by a project can change over time, which requires monitoring to track the changing value. "Consistent monitoring is essential and something that I hope people will invest in the Gulf," she said.

The second question is whether constructed reefs will be able to keep up with sea level rise. In addition, in places where they are able to keep up, what factors contribute to that success? "We want to make sure that we can learn from restoration projects that have already occurred so we can pick highly suitable locations," she said.

A third question involves the tradeoffs that occur when oyster reef projects are designed to maximize shoreline benefits. A community or other stakeholder group may be interested in supporting a project because of the coastal protection it provides, but the incorporation of additional ecosystem services into a project's goals inevitably involves tradeoffs.

A final question involves monitoring the performance of projects during disturbances such as storms or oil spills. Field data can quantify the benefits of a project, which can support decision making. "Communities want to see field-verified information," said Shepard, yet "we struggle to find any of that in the literature to show them." The data that are available tend to focus on erosion, but storm protection is the first thing people think about in terms of coastal protection. As a result, Shepard concluded, "there is an opportunity in the Gulf to set up monitoring stations related to storms, because we know we are going to get them."

During the discussion period, Shepard noted that many site-level questions remain unanswered and that these questions need to be answered as projects grow bigger and interact among themselves. She also addressed a broader concern, which is whether interventions need to be proven effective before they are used in a restoration project. Monitoring activities need to be adaptively managed, with lessons learned along the way informing future decision making, she said, even as restoration activities rest on a base of existing information about their expected effects.

MANAGING AN ECOSYSTEM SERVICE APPROACH

"Any efforts to monitor, access, and predict the status or the health of ecosystems services must consider environmental and social economic parameters, because by definition, ecosystem services are the benefits that humans obtained from ecosystems," said Sandra Werner, senior research scientist and environmental and regulatory advisor for ExxonMobil. This integrated approach requires a continuous dialogue between industry and non-industry stakeholders to gauge the priorities of stakeholders.

ExxonMobil, in collaboration with the Harte Research Institute, recently held a series of stakeholder workshops to engage in this dialogue, which included participants from industry, government, and academia. These workshops emphasized the importance of a holistic approach rather than focusing on the ecosystem services that matter to a particular constituent. For example, food, raw materials, and recreation consistently ranked among the top three ecosystem services for the offshore environment, and ecosystem services typically involved both nearshore areas and the deep Gulf.

With regard to the Gulf Research Program, Werner emphasized the importance of monitoring multiple stressors rather than just one. For example, many other factors affect ecosystem services in the Gulf besides the oil and gas industry, including fishing, transportation services, climate change, and ocean acidification. Considering all of the factors involved in the Gulf requires the calibration, verification, and refinement of an integrated modeling framework, Werner said. Such a framework would consist of coupled models, such as a hydrodynamic model coupled with a fish model, and it may need to consider subregions of the Gulf before being expanded to encompass the entire area. "Data to help calibrate, verify, and, over time, refine these models would be a good opportunity for the Gulf Research Program to pursue in the long term," she said. Box 3-1 highlights the potential role that could be played by modeling in a comprehensive environmental monitoring program.

Werner also discussed the key role played by biological communities in the deep Gulf, about which little is known at this time. (The deep Gulf is discussed in more detail in the next chapter.) For example, what is the spatial distribution of naturally occurring hydrocarbon seeps in the deep Gulf? What are the exchange mechanisms between deep seeps and the surface? How much of the released hydrocarbons reach the upper water column? Are they important contributors to upper water ecosystem services? Passive samplers could help answer these and other questions, especially as technologies continue to develop.

In the discussion session, Werner expressed some skepticism that all ecosystem services could be incorporated in a single model. Instead, many project-level questions need to be answered that can inform the larger framework, she said. "Any stakeholder could come up with a very long list of parameters that they would like to see monitored. The challenge for the Gulf region is to filter this [list] down to realistically achievable programs, set study priorities, and then adjust these priorities as data come in over time." In Werner's opinion, one way to do so would be to hold periodic workshops that bring together all the involved stakeholders to examine specific questions or priority areas. Such workshops could provide a better sense of where funds need to be invested to meet stakeholder and scientific needs.

BOX 3-1 The Role of Modeling

A model of an ecological system is an abstract, usually mathematical, representation of said system. Data collected from the ecosystem representing specific attributes of the system, ranging in scale from an individual population, to an ecological community or habitat, or even an entire biome can be studied to gain understanding of the real system. In contrast, a conceptual model can also be useful for developing understanding of a system by illustrating the relationships between major components of a system. It is a reasonable starting point for stakeholders as they identify and map out the major components of the system in question.

A particularly interesting exchange during one of the panel discussions involved the use of numerical models to fill gaps in existing data and monitoring systems. For example, Nancy Rabalais, executive director and professor of the Louisiana Universities Marine Consortium, observed that the model she and her colleagues use to explore the dynamics of hypoxia has become very sophisticated and can accurately hindcast the data they have collected over the years. "That's a very important part of the understanding."

Chuanmin Hu, professor in marine science at the University of South Florida, noted that models are critical in understanding the ecosystem "as a system and not just as a current point or current parameter." Without models, it would be very difficult to understand the connectivity between parts of the system, such as the deep ocean with coastal estuaries.

Pointing to the implausibility that a truly comprehensive monitoring program will be affordable, Jonathan Porthouse, senior manager with the National Fish and Wildlife Foundation, said that enough data nevertheless can be gathered to calibrate and validate models. These models then can be used to project the effects of proposed projects into the future. "Modeling is probably the only way you can get to questions about 'what if?'"

Rebecca Allee, fisheries biologist and senior scientist for NOAA's Gulf Coast Services Center, observed that models will have difficulty incorporating some relevant factors, such as living marine resources, but many parameters can be modeled. Coupling models with remote sensing then can yield "a great tool." Allee also emphasized the value of visualization tools to communicate the results of models for vetting management strategies. "If you can find a common theme, like sea level rise in the Gulf, and you can demonstrate its effects through visualization so that the community understands it, they're much more likely to support mitigation projects."

GULF RESTORATION PROGRAMS: EMERGING ROLES AND POTENTIAL FOR MONITORING

The NOAA RESTORE Act Science Program

Rebecca Allee, fisheries biologist and senior scientist for NOAA's Gulf Coast Services Center, leads the science plan development team for the RESTORE Act Science Program, which has been developing a long-term plan to guide the ecological and economic recovery of the Gulf Coast states.[1] One of the focus areas of the plan is "holistic approaches to observing and monitoring with advanced and innovative technologies to monitor fisheries, federal trust species, and other natural resources, and data integration tools focused on the observing needs in the Gulf of Mexico." As examples of this monitoring, the plan cites "observation and monitoring efforts to identify, map, and assess habitats, including poorly known deep-water habitats, including relevant physical and biochemical parameters" and "observation assets to monitor resources, including fisheries and protected species, and to enhance and improve fishery and wildlife management in the Gulf." However, NOAA does not have the resources to pursue these and the other research priorities in the plan on its own, said Allee. Instead, it is looking to partner with other organizations to leverage its resources.

She particularly emphasized the need for a comprehensive habitat inventory done at a high resolution and with consistent spatial and temporal sampling. As an example of the difficulties involved, she cited the zooplankton sampling done by the Southeast Area Monitoring and Assessment Program (SEAMAP). Because zooplankton are concentrated in different areas in the spring and in the fall, sampling is done nearshore or offshore, with long-term annual assessments. "We need to try to find more consistent ways of establishing those sampling sites."

A comprehensive inventory could be linked with the ecosystem services that each habitat provides, with a standardized and consistent approach taken for valuing those habitats, said Allee. This would provide a resource for the science and resources managers in the Gulf region, particularly in the prioritization of restoration projects. Furthermore, longer term trends such as climate change could be built into the valuations, which would assist with both adaptive management and gap analysis.

Finally, Allee pointed out that data prior to 1980 on ecosystems are largely lacking, which makes it difficult to do long-term trend analyses of either upper or lower trophic levels. "We need to have sustained monitoring programs, not just of the biological but of the physio-chemical environment." This will require partnerships to provide the needed spatial and temporal coverage. Even with the Gulf hypoxia program (described in the previous chapter), she observed, NOAA cannot maintain the monitoring on its own. "We've looking for partners and opportunities to leverage."

The Gulf Environmental Benefit Fund of the National Fish and Wildlife Foundation

Jonathan Porthouse, senior manager with the National Fish and Wildlife Foundation, briefly described the Gulf Environmental Benefit Fund, which is receiving money directed from court settlements from BP and Transocean to fund projects benefiting the natural resources of the Gulf Coast that were impacted by the spill.[2]

The funding available to programs like NFWF provides a "once in a lifetime opportunity" to approach the challenges facing the Gulf as "a single restoration project," Porthouse said. All organizations involved in the effort have a part to play in constructing a comprehensive program that has long-term impacts. "We don't want to spread random acts of restoration kindness around the coast," he said. "We are looking to find a way to take the restoration opportunity here, aggregate it, and get it to the point where it truly does produce measurable, trackable, and reportable ecosystem services."

The Fund's primary focus has been on habitats. "If we restore habitats appropriately, many of the ecosystem services we're looking to have benefiting the Gulf Coast will take care of themselves," Porthouse said. In the Gulf region, a focus on habitats encompasses coastal islands, barrier islands, beaches, dunes, bays, and estuaries. In particular, the fund is concentrating on oysters, red snapper and other reef fish, Gulf Coast birds, sea turtles, and marine mammals.

Monitoring is a critical component of the Fund's efforts. Monitoring helps the Fund determine whether a given project is meeting its objectives. "Is [a project] having the right physical and chemical effect on the environment? If so, does it actually have the ecological effects which you thought you were going to have?" Furthermore, monitoring is important not just under current conditions but as conditions change in the future.

Although the Gulf Environmental Benefit Fund is focused on restoring fish and wildlife habitat, it can incorporate some monitoring to inform other restoration activities. However, linking these efforts requires an overall plan or conceptual model that encompasses the entire suite of restoration activities, extending even

[1] The plan and more information about the program are available at http://restoreactscienceprogram.noaa.gov.

[2] More information about the fund is available at http://www.nfwf.org/gulf/Pages/home.aspx.

to activities such as tourism or education. A conceptual model would bring all of these activities together and reveal data gaps and the priority areas that need to be addressed. For example, a model could link the oyster fishery to the oyster fisher to community cohesion, with "very clear linkages between each of the nodes in the diagram," said Porthouse. It also would link the nearshore and the offshore, providing a way for activities in one area to stimulate activities in another, as well as bringing together the different groups involved in these activities.

Porthouse emphasized issues of geographic and temporal scale. Restoring an oyster bed is not the same as restoring an oyster fishery. Although they are related, they have different outcomes and data needs. Similarly, a short-term focus may mean losing sight of long-term trends, so that the signal gets lost in the noise. He also emphasized the need for mapping, such as subtidal habitat mapping, with consistent time scales and methodologies across states and regions.

The Gulf Research Program could provide a valuable service in supporting development of the conceptual model needed to coordinate restoration activities, Porthouse concluded. Such support could facilitate a conversation about data gaps, planning, and decision making. The Program also could evaluate programs as they move forward, both as individual entities and as parts of a greater whole.

MONITORING AND INDUSTRY

Long-term environmental monitoring can be extremely helpful to industry, observed Ruth Perry, a marine science and regulatory policy specialist with Shell Oil. Such monitoring can address baseline information gaps and bring value in managing risks. Companies can demonstrate compliance with environmental regulations based not on precautionary measures but on good science, which serves the purposes of both industry and regulators.

Perry mentioned several areas where the support of the Gulf Research Program could make a difference for industry. One is real-time ocean observing over extended periods. This could include not only physical oceanography but biological, chemical, and ecological monitoring programs incorporated into fixed and autonomous ocean observing platforms.

She added that the Gulf Research Program could support monitoring of the effects of activities on ecosystems, both on a local and more regional scale. Baselines and changes to baselines could be measured not only in the nearshore and offshore but in the deep Gulf, where data are much scarcer.

For its part, industry can contribute scientific and technical support to these efforts along with its experience in establishing joint industry projects. In particular, industry has an existing infrastructure of communication and power systems, platforms, and operations that could support monitoring efforts. Collaboration of industry trade associations and financial leveraging of stakeholders are other assets available from industry. Industry has many ongoing projects and activities that could inform a monitoring program in the Gulf. Both fixed platforms and autonomous vehicles could play a role in observations. From Shell's perspective, priorities are to integrate existing efforts, develop integrated ocean observing platforms, and make shared and accessible data available, said Perry. Industry recognizes that its data have value to multiple stakeholders, and though proprietary issues will always be a factor, much of the science work Shell is doing could be disseminated if the appropriate cyberinfrastructure were in place, Perry said. In particular, a centralized database that integrated existing data with new data could make information widely available to stakeholders.

Perry used marine sound as an example of the potential for collaborative research. An observing system that combined cabled instruments, existing platforms, autonomous underwater vehicles, and animal telemetry could serve many different needs in the region. However, developing such a system requires that local communities of interest be engaged, including academia and government, to leverage the strengths of existing organizations for the conduct of research and for data sharing.

IDENTIFYING DATA PRIORITIES TO SUPPORT MONITORING

Satellites, for example, provide a way to generate not just imagery but quantitative information about environmental issues in the Gulf. In essence, satellites can act as a "virtual buoy system," said Chuanmin Hu, professor in marine science at the University of South Florida, with the ability to place a virtual buoy wherever it is needed. They also can provide time series, which can be used to compare current conditions with baseline conditions.

However, satellite data cannot answer all questions, Hu acknowledged. But the kinds of data available from satellites can be extended to different regions, such as estuaries, and different parameters once new data products are validated. In addition, new technologies will create new opportunities for long-term monitoring. For example, NASA and the European Space Agency are currently planning future satellite missions that will have higher spatial and temporal resolutions.

The most important question, Hu emphasized, is what data are needed for monitoring. Many groups collect data from the Gulf. Leveraging and coordinating these data can both multiply the value of the data already being collected and reveal gaps in data coverage. Greater communication is the key to such coordination, he said, so that stakeholders know what data are available. Greater communications also can make clear to data providers what resource managers need.

Hu emphasized the need to prioritize in answering questions about the Gulf. "You cannot do everything," he said. "As a group, we need to prioritize what we do."

OBSERVATIONS OF THE BREAKOUT GROUPS

As noted earlier, participants broke into four breakout groups to discuss the two major areas of opportunity addressed during the workshop. The main points of the breakout groups are summarized here. Again, these observations should not be seen as the conclusions of the workshop participants as a whole. Nor are they activities that the workshop participants thought should be pursued by the Gulf Research Program. Rather, they are opportunities related to ecosystem restoration and related activities, with which the Program could consider.

Environmental Restoration: A Synopsis of the Discussion

- **Monitor the success of restoration, from the project level to the landscape level, including cumulative effects and unintended benefits.** Many restoration projects are often designed to be site or resource specific, but with the number and diversity of restoration projects being considered across the Gulf region, there is an opportunity to evaluate suites of related projects for their common successes and challenges. Such efforts may also inform managers of trends or patterns that may be only observable at larger or even landscape scales.
- **Monitor socioeconomic conditions, including community metrics.** As restoration projects are being developed, there is an opportunity to integrate local socioeconomic metrics as part of the evaluation of the restoration effort. A monitoring program of a successful environmental restoration project has the potential of capturing the linkages between human communities and the environment, which could facilitate public understanding of the value of a restored environment and its contribution to the local communities' economy and wellbeing.
- **Hold a workshop with stakeholders to prioritize coastal ecosystem services for study, including sites that need to be monitored as soon as possible before a restoration project begins.** Nearly all ecosystems provide a variety of ecosystem services, but the benefits and value of those services can vary geographically, and exploiting one service can negatively impact other services in both time and space. Engaging stakeholders via a workshop and characterizing the tradeoffs could inform the public and help them prioritize among the services to be restored.
- **Monitor fish tissue burden of contaminants, sediment burden and flux of contaminants, bird populations, and threatened or endangered species, including the effects of management on populations.** Following the *DWH* oil spill, there was considerable public concern about the fate and impacts of the remaining oil (and dispersants) that may persist throughout the food web and Gulf environment.
- **Monitor the habitat impacts of freshwater and sediment diversions to answer questions around effectiveness, including the effects on key estuaries.** Coastal wetland loss along the northern Gulf is a decades-long challenge that more recently has been exacerbated by sea level rise. Much of the loss is due to the lack of sediments being delivered into the wetlands by rivers that flow into the Gulf of Mexico. Freshwater diversions are a technique to address one cause of wetland loss—the failure to maintain elevations sufficient to support emergent vegetation forming the wetland habitats (Allison and Meselhe, 2010). There is a diversity of perspectives on the effectiveness of such diversions as well as concerns around the impacts of these efforts on fisheries, especially oysters (Melancon, 2010).
- **Use models to identify the restoration potential of ecosystems and to inform adaptive management, with consideration of changing baselines as, for example, sea level rises.** It is important to understand baseline ecosystem conditions, existing conditions, and to the extent possible, estimate ecosystem response to alternative management scenarios. Incorporating ecosystem process and function into restoration planning and implementation may improve the sustainability of restoration projects.
- **Conduct public awareness, education, and outreach campaigns to explain restoration science and the importance of the deep ocean, with assessments of effects of communications and education programs.** Until the *DWH* oil spill, the deep ocean was relatively unknown to the public. As restoration projects are being developed in the Gulf region, there is an opportunity to educate the public about the deep ocean and build awareness of its importance.
- **Involve communities in monitoring and research before, during, and after projects are undertaken.** Community engagement in areas targeted for research and restoration has the potential for advancing community stewardship of the resources and enhancing sustainability of the restoration projects.

4

Monitoring Needs in the Deep Gulf of Mexico

BOX 4-1 Important Points Made by the Speakers

- As industry pursues oil and gas into the deep ocean, much more needs to be known about these regions and the ecosystems and organisms they contain.
- Though the economic value of the services provided by the deep ocean is not fully known, its value is likely to be very large.
- A large array of technologic resources will be needed to understand physical, chemical, and biological processes in the Gulf, including gliders, buoys, air- and ship-based instruments, and satellites.
- Monitoring and research can be a good substitute for restoration of poorly understood regions such as the Deep Gulf of Mexico.
- If more people were exposed to education and outreach about the services the deep oceans provide, the perceived value of the deep ocean would go up.
- Industry will support marine research that has a sound business rationale.

AN INTRODUCTION TO THE DEEP OCEAN

The community of academics who study the deep ocean is not large—just a few hundred worldwide, said Robert Carney, professor in the School of the Coast and Environment at Louisiana State University. Part of the reason is the expense of studying the deep ocean, with the costs for ship time ranging up to and exceeding $100,000 per day. However, industry increasingly is pursuing oil into the deep ocean, whether off the coast of the eastern United States, Brazil, West Africa, India, Australia, or the Gulf of Mexico. As a result, coastal communities are facing threats from beyond the shallow water horizon with this offshore energy development, Carney said.

Many misconceptions about the deep ocean exist, Carney observed. He mentioned, for example, engineers who did not realize that a synthetic fitting in the deep ocean would be colonized by animals and biodeteriorate, the belief that all deepwater animals are biosynthetic, and the idea that the deep ocean has no effect on the surface ocean. Despite some myths and misconceptions being cleared up, much about the deep ocean is unknown.

Below the epipelagic zone in the first few hundred meters of the ocean, ocean water temperatures decrease to a low of about 4ºC in the Gulf of Mexico and about 2ºC in the Atlantic Ocean. The conditions of bottom water reflect both local processes and bathymetry and events occurring at a distance, Carney pointed out. For example, oxygen levels at these depths probably took 1000 years to reach these depths and under normal circumstances would persist for 300 years. During the *Deepwater Horizon* oil spill, some of this oxygen may have been consumed by hydrogen-digesting microbes, whose numbers exploded in response to the availability of oil. The resulting reduction in oxygen at these depths may slow the recovery by constraining other biological resources.

At the same time, sinking particles rapidly link the surface ocean to the deep ocean. In particular, deep waters play a very large role in the planet's carbon, nitrogen, and phosphorus cycling, in part because of the vast size of the deep ocean. The deep sea provides the last chance for biological remineralization before fossilization, Carney observed. In addition, the deep ocean has sequestered large quantities of chemicals in the past, which is one reason why industry is so interested in the region.

Because living things in the ocean depend primarily on detrital sinking, the biomass of ocean fauna decreases with depth. Yet fisheries do exist in the deep sea, typically populated by very old organisms. "These are very old fish that are being fished out—75 -year-old fish are going to market." Furthermore, the variety of organisms increases with depth. This is counterintuitive, Carney said, because the deep ocean would seem to be an exceedingly monotonous habitat, though perhaps it is much less homogenous than thought. The kinds of species in the ocean also vary by depth. "Between 200 meters and, say, 4,000 meters, you're probably going to turn over your species inventory three times. Does environmental protection policies change three times as you go down? No – the deep is considered homogenous and uniform."

Embedded within this vast heterogeneous system are chemosynthetic subsystems that do not exist in shallow water. For example, in the Gulf of Mexico, these communities start to occur at about 400 meters. Something unique about the deep sea ecosystem allows the persistence of chemosynthetic communities, Carney said—perhaps a lack of predation or something about the environment.

The Gulf of Mexico is a major basin within the Atlantic Ocean, with an extensive circulation between the Gulf and the broader ocean. Water is heated in the Gulf, flows along the east coast of the United States, and eventually warms Europe. The Gulf was once a much larger shallow ocean basin which is now filled with sedimentary structures, salt, and hydrocarbons. For example, the northern Gulf is characterized by an extensive salt layer, which is malleable and which provides conduits to the oil that industry is seeking. Tectonically, the Gulf is a failed spreading center that used to be active but is now a passive ocean basin. As Carney pointed out, the city of Jackson, Mississippi, rests atop one of the largest buried volcanoes in the United States, formed when tectonic processes were still active in the region.

The Gulf has a heavy sediment load from the decay of surrounding mountain ranges. New Orleans, for example, sits atop 8 to 14 kilometers of sedimentary structure filled with source rocks for hydrocarbons which serves as the basis of the petrochemical industry in the northern Gulf.

DEEP GULF RESEARCH: POTENTIAL FOR PARTNERSHIPS

Carney noted that the Macondo blowout illustrated the enormous challenge of responding to spills in deepwater environments, the potential for adverse effects of response and cleanup efforts, and the complex interactions between spilled oil, dispersants, and the biophysical properties of the surrounding waters. Even under normal conditions, operational offshore drilling activities can discharge produced waters (water that is released from wells with oil and gas), drilling muds, and cuttings. Federal agencies such as the Bureau of Safety and Environmental Enforcement are responsible for monitoring these activities, and the industry has established working groups to address pollution issues through trade organizations such as the Gulf region's Offshore Operators Committee and through nonprofit organizations such as the Petroleum Environmental Research Forum.

The oil and gas industry has stated that it is willing to partner with existing monitoring and observation programs run by such organizations as GCOOS and NOAA. Carney believes that collaboration between industry and academia also can bring technological innovation into deep water, as illustrated by the Deep-ocean Environmental Long-term Observatory System that has been deployed by BP and several academic institutions off the coast of Africa, which is designed to determine long-term natural environmental conditions near and far from operating platforms. There are likely many other emerging technologies and methodologies that both the public and private sector will develop and apply to better understand and manage one of the most important ecosystems in this country, Carney concluded.

UNDERSTANDING THE DEEP OCEAN

The restoration activities responding to the *Deepwater Horizon* oil spill took place largely on the coast, yet this was an oceanic spill, said Mark Benfield, professor in the Department of Oceanography and Coast Sciences at Louisiana State University. Though approximately 25 percent of the oil was recovered, the majority of it remained in the open ocean at a variety of depths. The restoration activities occurred on and near the coast because that region is accessible, it is close to many of the perceived stakeholders, and much more is known about coastal ecosystems than about deep ocean systems. "How do you restore something you don't understand?" asked Benfield.

In such circumstances, monitoring and research can be a good substitute for restoration, Benfield said. The deep ocean is an extremely complex, coupled physical, chemical, and biological system with a variety of activities taking place from the surface to depth. Understanding what to monitor is a challenge in itself, but baseline information is needed to detect change. This baseline information was largely missing for the *Deepwater Horizon* spill Benfield noted. "We didn't have the before and the control information," he said. "We were able to gather a lot of data afterwards but not before, so that was the real challenge."

Nonetheless, some sources of baseline data are available, especially with the cooperation of industry. Potential data sources include oil and gas industry's Acoustic Doppler Current Profilers (ADCPs), remotely operated vehicles, and autonomous underwater vehicles. For example, existing ADCPs on platforms can detect vertical migration of plankton over the course of the day and over the course of the seasons. When the oil from the *DWH* spill entered the water column, the patterns of plankton movement changed near the well but not at more distant locations. "We can use this kind of data to infer what's going on across the Gulf," Benfield said.

Benfield also discussed the use of remotely operated vehicles to do biological and hydrographic monitoring. The oil and gas industry uses these vehicles to perform a variety of tasks at sea, creating an opportunity to gather scientific data by installing them with sensors. Such data could be used to establish baselines for marine monitoring as well as servicing deep sea observatories.

ECOSYSTEM SERVICES FROM THE DEEP OCEAN

Ecosystem services are the benefits that humans derive from nature that affect human well-being, said David Yoskowitz, chief economist for NOAA and on leave as the Endowed Chair for Socio-Economics at the Harte Research Institute at Texas A&M University-Corpus Christi. But discussions of these services often overlook two critical issues: the demand for these services, and the links between ecosystem structure and function and human well-being.

Much is not known about the ecosystem services provided by inshore and nearshore environments, Yoskowitz observed, and even less is known about the services provided by offshore environments. The value of ecosystem services manifests itself in the demand for those services. The question then becomes how to assess this demand. As described by Sandra Werner (see the section "Managing an Ecosystem Service Approach" in Chapter 3), the Harte Research Institute held two workshops in 2013 that looked at offshore ecosystem services through the eyes of a small group of stakeholders, including representatives of the oil and gas, fishing, and recreational industries along with a variety of people from the governmental and nonprofit sectors. The workshop participants tended not to emphasize their own narrow interests, Yoskowitz said. Instead, they generally thought more holistically about the potential provision of offshore ecosystem services, including the value of research and education. Though the group was relatively small and more work needs to be done, it provided a "reasonable understanding of the supply of ecosystem services."

One potential task for the Gulf Research Program, said Yoskowitz, would be to help close the gap of understanding between the structure and functioning of the offshore environment and its impact on human well-being. Such an effort could encompass not only the physical health of individuals but the emotional and psychological health of communities.

A major problem, said Yoskowitz, is that the techniques to determine the value of ecosystem services in the inshore and nearshore environment will not translate easily to the offshore environment. Ecosystem assessments tend to be two-dimensional nearshore, but they are three-dimensional offshore. Certain services may be localized to a specific depth or to the entire water column. The Gulf Research Program could "partner in the bigger effort to get at a more complete assessment of demand for offshore ecosystem services in the Gulf of Mexico," he said.

During the discussion period, Yoskowitz responded to a question that provoked a more general dialogue: the ways in which U.S. researchers are coordinating their work with researchers from Mexico and other countries that border the Gulf of Mexico. Yoskowitz briefly described a recent project known as "Gulf 360°: State of the Gulf of Mexico" that brought together Cuban, Mexican, and U.S. researchers to harmonize socioeconomic data from the countries surrounding the Gulf.[1] Other workshop participants described similar efforts in a variety of disciplines while also pointing to the barriers to such efforts, including difficulties accessing proprietary data and bureaucratic obstacles within governments.

Yoskowitz also spoke to the issue of education and outreach in response to another question. Members of the general public might know something about the nearshore environment, but they are probably going to know much less about the deep ocean. "To me, the biggest advance we could make is not valuing the ecosystem services but educating about them," he said. If more people knew about the services the deep oceans provide, the perceived value of those services would go up.

INDUSTRY MARINE RESEARCH AND THE POTENTIAL FOR GLIDERS

The oil and gas industry has supported some notable marine research, though this research is often not published in the scientific literature. In 1982, industry researchers did the first comprehensive survey of the loop current and its eddy by measuring the velocity

[1] More information is available at http://gulf360.org.

field using a new instrument known as an Acoustic Doppler Current Profiler. Measurements of loop current and eddy track and intensity were developed into a historical archive in 1986, with updates every two or three years since then. In 1992, industry researchers published the first paper suggesting that the loop current and hurricane intensity are coupled. In 1999, the first comprehensive measurements of the Yucatan flow through were made, which required cooperation with both the U.S. Navy and Cuba to acquire current meter data.

In 2000 the first model and field study of the rise of oil and gas from a deepwater blow-out were made, followed by the first network of deepwater real-time ocean current measurements in 2004. In 2005, E&P Sound and Marine Life Joint Industry Program initiated multimillion-dollar studies of marine sound and its impact on critical species. The first study of the effect of global warming on hurricanes in the Gulf was done by industry researchers in 2011, followed by the first operational forecast circulation model using ensemble modeling in 2014. According to Cortis Cooper, a Chevron Fellow with the Chevron Corporation, who participated in much of this research, this work has not been well publicized, but it represents major steps forward.

Industry has extensive offshore infrastructure and experience that it can bring to research partnerships, Cooper said. It also has large proprietary marine databases, though it is often reluctant to share those databases, especially with competitors. Industry has extensive networks of world-class technical experts, both within and outside of companies. However, with a few exceptions, research is not a core business concern—Cooper estimated that his company spends perhaps a few million dollars a year on joint research projects. "You really need to have a sound business reason to do marine research," he observed. "Trying to argue that it's going to provide good will or advance science will count, but they're typically not sufficient on their own to justify an investment."

Cooper briefly described some of the existing R&D consortia involving industry. The Climate and Simulation of Eddies and Eddy Joint Industry Projects (CASE/EJIP), which Cooper helped start in 1983 and which currently has 18 member companies, has been spending an average of about $250,000 a year for more than 30 years to look at extreme wind, waves, and currents in deep water, with a somewhat expanded focus in the last decade. The DeepStar consortium, which began in 1991, has a budget of about $1 million per year, with roughly $200,000 a year spent on physical oceanography topics. The Offshore Operators Committee, which has been in existence since 1948 and includes 70 companies and contractors, works on problems involving offshore pollutants when enough companies are interested in a particular project. The Petroleum Environmental Research Forum, begun in 1986, focuses purely on environmental research, again when enough companies are interested in a problem to fund the necessary research. The E&P Sound & Marine Life Joint Industry Program, with 12 companies involved, have been spending an average of about $7 million per year supporting research to help increase understanding of the effect of sound on marine life generated by oil and gas exploration and production activity on marine sound research. And, finally, the Long Term Environmental Monitoring Forum is an ad hoc group of five companies formed in 2013 to discuss long-term environmental monitoring.

After this overview of industrial research, Cooper focused on the possibility of establishing a public/private sector partnership to set up a glider network for the Gulf of Mexico. The basic concept, he said, would be to maintain a fleet of something like ten subsurface gliders that would continuously monitor the Gulf for at least several years. These gliders can offer controlled profiling of the water column and measure velocity; conductivity, temperature, and depth; dissolved oxygen; chlorophyll; hydrocarbons; turbidity; and acoustics. Today they can descend to about 1,000 meters, but within ten years they likely will be able to dive to the bottom of the Gulf of Mexico—to depths exceeding 4,000 meters. Instead of remaining at the surface and going only where currents take them, gliders can be sent "where you want them to go," said Cooper. As analytic technology continues to develop, Cooper suggested they soon could fingerprint oil using mass spectrometry, do genetic testing of organisms, and measure acidification of the water.

Industry is interested in gliders because of their ability to monitor marine mammals, quantify anthropogenic sound, track the loop current and eddies, track oil spills, identify sources of unknown slicks, track the fate and effects of pollutants, and assist search and rescue, said Cooper. For other stakeholders, gliders could monitor harmful algal blooms, measure hypoxia, track climate change, measure sediment transport, monitor restoration impacts, and explore the lower water column of the deep Gulf.

Cooper pointed to several benefits a glider network could have for the Gulf Research Program. They are an innovative and forward-looking technology that could cover many needs expressed by stakeholders. They are not redundant with other technologies and provide a rapid response capability in the event of another major spill. "Imagine if you had ten gliders out there. Within a matter of a day or two, you could quickly bring them into and surround an area like a *Deepwater Horizon* and begin sampling very quickly." They would build a foundational capability in the Gulf by bringing together partners and leveraging funds. They also have an appealing educational and outreach component.

Cooper also briefly discussed the potential use of some of the industry's offshore facilities as moorings for environmental monitoring sensors. Industry currently has extensive coverage in the Gulf with about 4,000 offshore platforms. They could provide a great deal of information to use in model simulations or to monitor the presence or absence of the loop current. There are historical precedents for the use of offshore platforms for such purposes, such as the cooperative agreement between Shell and NOAA to feed Shell's real time meteorological information into forecasting systems. There are also challenges to the use of offshore platforms, Cooper noted, including building trust, establishing and maintaining funding, and finding a business driver that will motivate industry to cooperate. But if a solid business case can be found, industry has many resources that it can contribute to environmental monitoring projects.

During the discussion period, Cooper pointed to the many advantages of combining satellite imagery with data from a glider network. Gliders can track slow-moving features, while satellites can monitor changes that occur more quickly, and a suite of gliders could provide large areal coverage.

DATA PARTNERSHIPS

Five years after the *Deepwater Horizon* oil spill, some sources of funding to respond to the spill are declining while others are coming on line. That makes the present a good time to think collectively and holistically about the best ways to address current issues, said Pasquale Roscigno, chief of the Environmental Studies Program for the Gulf of Mexico Region for the Bureau of Ocean Energy Management (BOEM). BOEM has engaged in a number of partnerships with other organizations focused on such issues as ocean current monitoring, seafloor habitat mapping, and protected species observations. "We've had a lot of opportunities for partnerships," he said.

As an example, he described the long-term monitoring program of the Flower Garden Banks, which is about 100 miles offshore of Galveston, Texas. For almost four decades, the program has monitored the corals and their ability to recover from hurricanes and other disturbances. "It's a great success story between BOEM and NOAA—to manage the system in the middle of an oil field." Recently the program has installed an ocean acidification sentinel, in partnership with Shell, to get a sense of how changing oceanic chemistry is affecting the area. This activity "is a good example of where, with good faith and good resources, we can extract oil and still protect the environment," Roscigno said.

Another successful program has been the installation of Acoustic Doppler Current Profilers (ADCPs) on platforms, though originally this program was met with industry resistance. This resistance was largely overcome, however, as industry became aware of the value of these data in determining how water currents were affecting riser structures. Roscigno added that this program is now being renewed, which creates new opportunities to install additional sensors and expand their capabilities.

One of BOEM's responsibilities is to ensure that seafloor habitat mapping is done before industry disturbs an area. This activity has enabled the use of three-dimensional seismic data to predict chemosynthetic and deepwater coral distributions. It also has resulted in the creation of seafloor maps of the seeps in the Gulf of Mexico, which were used to help locate the oil from the *Deepwater Horizon* spill.

A final example Roscigno cited is noise in the sea from anthropogenic acoustic inputs such as the decommissioning of oil platforms. A recent BOEM study (Berchok et al., 2014) has documented the need for a future Passive Acoustic Oceans Observing System or regional Passive Acoustic Monitoring programs.

BOEM collects a great deal of data in a very successful partnership with other agencies and the private sector, said Roscigno. What is still needed, he continued, is a central place where metadata and perhaps original data can be located so that scientists can access this information rapidly. "It's a hard thing to do to get different agencies and organizations to agree to some standards for the data," he said. "But, again, the opportunity is strong at this point to get that virtual backbone infrastructure in place and link up these systems." (Data issues are also discussed in the section "Data Requirements for Environmental Monitoring" in Chapter 2.)

BOEM has had great success partnering with other stakeholders, and additional funding creates an opportunity to extend that success, Roscigno concluded. "Let's partner and partner and partner!"

SATELLITES

An array of resources will be needed to understand physical, chemical, and biological processes in the Gulf, said Antonio Mannino, research oceanographer with the Ocean Ecology Laboratory at NASA's Goddard Space Flight Center, including gliders, buoys, and air- and ship-based instruments. Another critical resource is space-based measurements. Satellites can observe through the first optical depth of the oceans in the nearshore, inner shelf, and outer shelf. With different instruments and satellites, NASA can produce data products with a wide range of temporal, spatial, and spectral specifications. These data can provide information on such factors as particle absorption, dissolved organic matter, phytoplankton type and abundance, turbidity, sea surface salinity, winds, and sea surface height.

Mannino noted that NASA also has access to measurements from ships, airplanes, and autonomous underwater vehicles, and it supports technology development to extend the capabilities of instruments. In addition, other countries produce oceanic satellite data that can complement NASA's data, and NASA is planning new missions that will gather additional information.

Different missions and instruments have contrasting advantages and disadvantages. For example Mannino continued, low-earth polar-orbiting satellites can have gaps in coverage or can lose data because of sun glint or high view angles. Geostationary satellites are farther away but can monitor areas from the same location continuously over time. As examples of the kinds of events that can be tracked using geostationary satellites, Mannino mentioned harmful algal blooms, eddies, surface currents, coastal hazards, and tidal processes. High-frequency satellite observations also can be used to evaluate coastal models and improve model forecasting.

To design future missions that would be useful to the Gulf Research Program and other operations in the area, satellite designers need to know user requirements for temporal and spatial coverage, products, and real-time data, Mannino said.

DEEP SEA MINING AND ITS IMPACTS: A CASE STUDY

Before the middle of the 20th century, salt marshes were generally viewed as having little value, noted Cindy Lee Van Dover, Harvey W. Smith Professor of Oceanography at Duke University's Nicholas School of the Environment. They were drained, filled in, and replaced by highways, airports, parking lots, housing developments, as well as garbage, ash, and dredge dumps. Only since the 1960s, as scientific understanding of their ecosystem roles expanded, have salt marshes been recognized for the wide range and value of the ecosystem services they provide.

"We could repeat the same thing in the deep sea by not appreciating the ecosystem services it provides," said Van Dover. The deep sea provides primary and secondary production, nutrient regeneration, and habitat. It produces fish, oil and gas, minerals, energy, therapeutic agents, and biotechnology products. Though the economic value of these services is not fully known, that value is likely to be very large (Armstrong et al., 2012; Thurber et al., 2014).

Since 2005, Van Dover has been working through an industry-university partnership on the ecological consequences of a deep sea mining project, and she described that work as an example of scientific work in the deep sea. A Canadian company known as Nautilus Minerals, Inc., has been developing a plan to do open cut mining of the seafloor off the coast of Papua New Guinea using equipment operated from a surface ship. While such mining would destroy sections of the seafloor, it could be less environmentally destructive than mining mountain tops, polluting watersheds, and displacing human communities.

Van Dover and her colleagues were asked to help develop a monitoring plan and assessment of environmental impact. The monitoring plan includes preliminary surveys, field monitoring analysis, database analysis, assessment, and dissemination of information, which is "fairly straightforward" compared with some of the monitoring plans that have been discussed for the Gulf, said Van Dover. The plan recognizes that mining will have a number of environmental impacts, including loss of habitat, modification of habitat quality, modification of fluid flux regimes, sediment plumes and sedimentation, light and noise, filtration of bottom water near vents, and plumes from return water (Van Dover et al., 2014). These impacts will in turn have biological consequences, including elimination or reduction of local populations; decreased reproductive output; loss of larvae and zooplankton in riser systems; local, regional, or global extinction of endemic or rare species; decreased seafloor primary production; altered trophic structure; decreased diversity at the genetic, species, and habitat levels; and mortality or impairment due to toxic sediments. Finally, there are potential cumulative effects, including chronic regional losses of brood stock, genetic diversity, species, trophic interactions and complexity, and resilience; changes in community structure; genetic isolation; species extinctions; species invasions; and loss of knowledge and other future opportunities. Monitoring of these impacts can assist in improving their mitigation, up to and including cessation of the activity, Van Dover said.

Van Dover has been working on a site called Solwara 1, which is in the Manus Basin off Papua New Guinea. A nearby area known as South Su has been serving as a reference area and will remain unmined. A major focus of the monitoring to date has been biodiversity: what species are there, what is their spatial distribution, and whether South Su can act as a reserve for species (Collins et al., 2012). Community structure comparisons include species richness (as measured by univariate statistics), species composition (as measured by presence or absence), and species-abundance relationships (as measured by multivariate statistics). A nested sampling plan gathered 54 samples from the two sites: three assemblages at each site, three mounds at each assemblage, and three patches at each mound. This number could be reduced, Van Dover said, to acquire time series samples.

Another focus of the project has been genetic diversity, and particularly the level of endemism among sites. Studies of several vent species, including a black snail, squat lobster, and two species of barnacles, have revealed a fair amount of endemism, but less at the species level than at the genera level (Collins et al., 2012). However, for some species that can travel great distances, genetic differences are not significant across the sampled sites. The same approach has been used in the Gulf to show, for example, that some species are limited to the Gulf while others can be distributed well beyond Gulf waters.

Impacts on biodiversity from a mining activity, whether on land or under the water, can be avoided, minimized, or rehabilitated, Van Dover observed. They also can be offset, even to the extent of having a net positive impact. According to the International Marine Minerals Society, corporations have a responsibility for environmental management of marine mining.[2] In a rehabilitation and decommissioning plan, this responsibility is to include rehabilitation in conceptual designs, develop rehabilitation plans and targets, monitor rehabilitation performance, account for rehabilitation costs, establish progressive rehabilitation, and use adaptive management strategies. Although this code takes the form of recommendations rather than laws, it is "the gold standard for deep sea mining right now," said Van Dover.

For the Solwara 1 site, the immediate objective for the rehabilitation plan was to reestablish the three-dimensional mounds and fauna. Measures of success were survival, growth, and recruitment of organisms from elsewhere. The specific restoration activity would be animal relocation onto artificial substrata to facilitate recovery, with replication of treatments and controls. The costs of such an activity, with the cost models used in academia, can be extremely high, Van Dover pointed out. But the costs may be much less for industry, which already has ships available for use, greatly reducing the potential costs.

Van Dover also briefly described two other mapping projects. The first was a habitat monitoring project in the deep Pacific off the coast of Mexico. To preserve biological communities in areas claimed for manganese mining, Wedding et al. (2013) proposed using available data on 400-km by 400-km blocks to locate areas of particular environmental interest (known as APEIs). This represents "an interesting way to use data sets that are readily available but to combine them in ways that are important for monitoring." The second project used acoustic signals to detect methane seeps off the Atlantic Coast, which in turn can be used to map the densities of animals (Brothers et al., 2013; Wagner et al., 2013; Skarke et al, 2014). Furthermore, this work can be done through a telepresence technology, with the data gathered on one day informing the next day's mission. "You can be a deep sea biologist without even going to sea. It's a new world for understanding deep oceans."

Van Dover drew several lessons for deep sea monitoring from her experiences. One is that the scientific value of monitoring is often at least as great for monitoring per se and for environmental management needs. Another is that habitat mapping for baselines can be used in models to quantify ecosystem services. Oceanographic models can be used for hypothesis testing and assessment of impacts, especially with regard to connectivity, she said. Also, genetic approaches offer a relatively low-cost and high-resolution method for assessing natural resource management units, population structure, and the directionality of gene flow. Finally, process studies benefit from long-term monitoring and predictive modeling approaches.

OBSERVATIONS OF THE BREAKOUT GROUPS

At the end of each day during the workshop, participants broke into four breakout groups to discuss environmental monitoring opportunities with a focus on the two major areas of interest—ecosystem restoration and the deep Gulf. These observations should not be seen as the conclusions of the workshop participants as a whole. Nor are they activities that the workshop participants thought should be pursued by the Gulf Research Program. Rather, they are opportunities related to environmental monitoring and related activities, with which the Program could be involved as it develops in future years.

The Deep Gulf of Mexico

The deep ocean regions (deeper than 2000m) of the world constitute some 60 percent of the earth's surface and much of it has never been explored and much less than 1 percent has been directly observed (Smith et al., 2009). Our current understanding of the deep Gulf of Mexico is not notably better, so consequently, any discussion of monitoring of the deep Gulf involves establishing baseline information on the biodiversity, population connectivity, biogeography, and a complex suite of physical and chemical variables that include

[2] The code is available at http://www.immsoc.org/IMMS_code.htm.

currents, salinity, and carbon cycling throughout the water column. Virtually all of the observations below made during the workshop breakout session focus on the tools (maps, buoys, gliders, etc.) and monitoring targets (currents, biota, water column, pollutants, nutrients, temperature, etc.) that would help researchers improve understanding of the deep ocean ecosystem and its contributions to the larger Gulf of Mexico.

- Benchmark biological observations (pelagic to benthos, including microbial communities), with particular attention to particle and dissolved flux, deep currents and advection, descriptive sampling of the mesopelagic, understanding of Gulf and Caribbean ventilation, and hydrocarbons.
- Gather pelagic data on marine and avian organisms, including high-resolution imagery for individual organisms and data for damage assessments.
- Monitor biological, physical, and chemical variables in the water column and sediment, where possible in real time.
- Establish reference profiles of stratified deep water.
- Map habitats in three dimensions and their changes over time, including types of habitat and competing uses.
- Map benthic and benthic-associated habitats in the deep ocean, including pilot projects with industry to map seafloor habitat in select sites to encourage the release of bathymetric data.
- Monitor upwelling and downwelling to understand the transport of nutrients to the shelf, using gliders, buoys, and satellites.
- Monitor subsurface movement of particles for fisheries and beach closures, including the influence of the loop current.
- Monitor deep ocean currents to assess contaminant movements, with the use of moorings and echo sounders in selected areas of the deep sea to validate ocean models.
- Investigate toxicology for deep sea model organisms.
- Monitor ocean heat content to understand the effects on species migrations and climate.
- Understand the soundscape to establish baselines and to understand the behavioral impacts and nonlethal effects of anthropogenic sound on marine mammals.

Technology Development

- Support development of new technologies, including biomarkers, sensors, satellite telemetry, adaptive sampling, and improved analytic methods.
- Support technologies to increase measurement ability and to reduce cost of technology replication.
- Develop new methods for adaptive sampling and investigate how to prioritize and optimize sampling.
- Develop better quality control, calibration, and validation for Acoustic Doppler Current Profilers for the deep Gulf, including more accurate sensors.
- Develop Gulf-wide high-frequency radar systems.
- Develop new technologies such as ferryboxes to take advantage of existing opportunities.
- Explore innovative technologies and methodologies, such as the use of historical data linkages and data mining.
- Explore innovative technology development mechanisms, such as open source technologies, prizes, and grand challenges.

5

Workshop Synopsis

BOX 5-1 Important Ideas Offered by the Workshop Participants

The views contained in the report are those of individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Research Council.

- Conduct public awareness, education, and outreach campaigns to explain restoration science, as well as the importance of the deep ocean.
- Recognize that job training and the long-term involvement of the residents of affected areas could increase the success of monitoring and restoration activities.
- Develop a clear set of questions that guide the design of a Gulf monitoring effort.
- Build a first-order ecosystem services model and use it to develop system understanding and guide future monitoring, including where to monitor, the spatial and temporal resolution, and the most effective deployment of technologies.
- Monitor socioeconomic conditions, including community metrics to understand the Gulf region's demand for ecosystem services and their valuation.
- Use models to identify the restoration potential of ecosystems and to inform adaptive management, with consideration of changing baselines due to, for example, sea level rise.
- Support development of new technologies, including biomarkers, sensors, satellite telemetry, adaptive sampling, and improved analytic methods.
- Map habitats in three dimensions and their changes over time, including types of habitat and competing uses
- Partner with the oil and gas industry to map benthic and benthic-associated habitats in the deep ocean to encourage the release and utilization of bathymetric data.
- Monitor upwelling and downwelling to understand the transport of nutrients to the outer continental shelf, using gliders, buoys, and satellites.
- Monitor deep ocean currents to assess contaminant movements, with the use of moorings and echo sounders in selected areas of the deep sea to validate ocean models.

The Gulf region supports a wide variety of environmental monitoring programs, many with extensive histories of observations and data analyses that have informed scientists and decision makers alike. Like most large coastal regions in the United States, the fragmented nature of the many programs and their objectives reflect the priorities of national, state, and local jurisdictions, not to mention the assortment of scientific questions that industry, NGO and academic researchers have worked to address over the past decades. However, the scope and scale of *DWH* oil spill highlighted the need for greater coordination and management of the monitoring data collected so that scientists and policy makers could better understand the impacts of the spill at an ecosystem level. As the region also faces other environmental stressors and changes, a regional approach may be the only way that managers will be able to effectively mitigate some of the impacts stemming from these large scale changes.

A regionally focused environmental monitoring program or network for the Gulf of Mexico will be a major, multifaceted, and expensive operational challenge. Identifying user needs and cutting-edge technologies and methodologies, and coordinating efforts could be effectively accomplished by a broad partnership. A key requirement for a regionally focused monitoring network will be data management. Federal agencies such as NOAA (see chapter 2 discussion on data management) have developed programs to help stakeholders manage their data, but other Gulf-focused programs have been developed, most notably the Gulf of Mexico Research Initiative's Information & Data Cooperative (GRIIDC), which has developed a significant amount of data management infrastructure and has a thousand researchers from around the world submitting data.[1]

Opportunities to implement a regional ecosystem restoration strategy have already arisen, and more are likely to materialize over the coming few years. These opportunities include the enactment of the 2012 RESTORE Act, the Natural Resource Damage Restoration process, and the funding of the nongovernmental Gulf Environmental Benefit Fund managed by the National Fish and Wildlife Foundation. The Gulf Coast Ecosystem Restoration Council, the Natural Resource Trustees, and the Gulf Environmental Benefit Fund all have indicated their commitment to applying strong science and engineering in the selection, design, execution, and assessment of projects. However, it is unclear at this point how they will provide for needed research, modeling, monitoring, and assessment. Restrictions likely will limit their ability to commit significant resources for science, other than as necessary for design and evaluative monitoring of specific restoration projects.

In short, many questions remain, in part due to the unprecedented level of resources that will be committed to ecosystem restoration, the challenges inherent in coordinating the Gulf States and federal agencies' focus and efforts, and the substantial science and engineering challenges associated with design and assessment. The risks of poorly informed decision making are high.

The Gulf Research Program plans to take advantage of existing opportunities and catalyze new ones. While it is not the responsibility of the Program to undertake restoration or to provide the robust scientific foundation needed for this long-term undertaking, it will seek to leverage funds and contribute to long-term and regional strategies that bridge monitoring and restoration efforts. The suggestions of the workshop breakout groups for potential activities (see Chapters 2, 3, and 4) highlighted the rich opportunities that are present both to improve human well-being in the Gulf Coast region and to advance science.

In summarizing the key suggestions from the workshop, it might be useful to frame them in the context of the Program's goals. While the tools and approaches used in environmental monitoring can support all three Program goals, the workshop focused on opportunities to use environmental monitoring to achieve Goal 3—*advance understanding of the Gulf of Mexico region as a dynamic system with complex, interconnecting human and environmental systems, functions, and processes to inform the protection and restoration of ecosystem services* (NRC, 2014a).

Goal 3 may be the most fundamental and broad of the Program's goals, so there were many suggestions from the workshop that could support this goal. One of the challenges for all monitoring programs is developing and sustaining support over the life of a program, so effective communication is viewed as an essential tool for generating support for these efforts. With the substantial level of investment stemming from the *DWH* spill, there is a great deal of public interest in "how the money will be spent," coupled with the public's concern regarding the impacts of the spill on local resources. This level of interest provides a rare opportunity for education and outreach efforts by scientists and managers to conduct public awareness, education, and outreach campaigns to explain restoration science and the importance of the deep ocean, with assessments of effects of communications and education programs. These efforts to engage the public could be further augmented via job training and the long-term involvement of the residents of affected areas which can influence the success of monitoring and restoration activities.

Understanding the large marine ecosystem of the Gulf is a daunting goal, and as noted in the presentation on the Gulf Coast Ocean Observing System buildout plan, there are a large number of questions, needs and objectives identified by the stakeholders in the region. However, most successful monitoring programs have been shown to address a small or finite number of questions so the development of a set of questions that need to be answered could drive the design of a Gulf monitoring effort—an important step moving forward. A number of the workshop presentations discussed ecosystem services as a metric or approach for use with the various restoration efforts underway or in development. Our current level of understanding of the ecosystem services of the Gulf is limited, but research to understand the function and processes of the Gulf ecosystem is a necessary step in quantifying and prioritizing those services and their benefits to the communities around the region.

Given the complexity of the Gulf's services, scientists often turn to models in order to advance their understanding, so to build a first-order ecosystem services model and use it to develop system understanding and guide future monitoring, including where to monitor, the spatial and temporal resolution, and the most effective deployment of technologies would be a useful long-term Program goal. Any comprehensive research of the Gulf's ecosystem services would benefit from monitor-

[1]Gulf of Mexico Research Initiative Information & Data Cooperative, http://data.gulfresearchinitiative.org/

ing of socioeconomic conditions, including community metrics which is an important step in understanding the region's demand for those services and their valuation. As researchers look to support restoration efforts, they can use models to identify the restoration potential of ecosystems and to inform adaptive management, with consideration of changing baselines as, for example, sea level rises.

One of the key needs for advancing our understanding of the Gulf through monitoring will be through investments for technology development. Current monitoring efforts are often challenged by the costs of monitoring, especially in deep or remote locations that can cost upwards of $100,000 per day for ship time. New innovations and technologies are being developed and applied to monitoring objectives that will reduce costs, improve sampling, and provide validation for existing monitoring efforts. The suggestion to support development of new technologies, including biomarkers, sensors, satellite telemetry, adaptive sampling, and improved analytic methods captures this sentiment.

The deep Gulf presents the challenge of vast scale coupled with considerable unknowns regarding the ecology and biogeochemistry across three dimensions for any monitoring program, so prioritizing opportunities may be a useful step. Thus, opportunities that are foundational to advancing our understanding of the deep are such a priority. Mapping habitats in three dimensions and their changes over time, including types of habitat and competing uses could provide key insights into the distribution of important species (e.g., corals and marine mammals) and the movement patterns of nutrients and pollutants. The oil industry has a great deal of data, much of which is proprietary, from their exploratory surveys in the deep Gulf. An opportunity for partnering and sharing resources was articulated; in the efforts to map benthic and benthic-associated habitats in the deep ocean, consider including pilot projects with industry to map seafloor habitat in select sites of mutual interest—all to encourage the integration of private and public sector bathymetric data. Many workshop participants thought that these kinds of collaborations will be needed for all stakeholders interested in monitoring the deep, whether it is to leverage costs, share data, or work to protect living marine resources. Another major interest for monitoring the deep Gulf is developing a better understanding of the ecosystem services, such as the provisioning of nutrients into the food web of the Gulf. This can be accomplished in part by monitoring upwelling and downwelling to understand the transport of nutrients to the shelf, using gliders, buoys, and satellites. Tracking the transport of pollutants from the deep, a phenomenon unfortunately highlighted by the *DWH* spill, is another opportunity for advancing our understanding of the deep, so monitoring deep ocean currents to assess contaminant movements, with the use of moorings and echo sounders in selected areas of the deep sea to validate ocean models could help support that opportunity.

In combination with the earlier workshop on education and training and the subsequent workshop on community resilience and health, the workshop on environmental monitoring demonstrated how much could be gained by applying the National Academies' strengths in objectivity and independence within a collaborative process. The insights from all three workshops will provide the Gulf Research Program and its advisory board with valuable ideas and suggestions for the development of the program.

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A

Workshop Agenda

Opportunity Analysis Workshop for Environmental Monitoring

September 3-4, 2014

Hotel Monteleone
New Orleans, LA

Workshop Objectives:

1. Inform the Gulf Research Program Advisory Board and staff of concrete opportunities for the Program to develop and support in the realm of environmental monitoring.
2. Identify the environmental monitoring needs for a) developing ecosystem services models that in turn can inform habitat restoration, and b) improving the understanding of the physical and biological attributes of the deep Gulf of Mexico to enhance environmental protection from the impacts of oil exploration in the deep and ultra-deep water.
3. With respect to these themes, identify any areas for innovation and long-term monitoring, identify and discuss what other entities are already addressing or attempting to address those needs, and identify opportunities and mechanisms for potential partnerships.

WEDNESDAY, SEPTEMBER 3, 2014

Vieux Carre Room—Rooftop

8:30 a.m. Breakfast

8:30 a.m. Welcome and Gulf Research Program Overview
Kim Waddell, Gulf Research Program

8:45 a.m. Overview of the Workshop Objectives/Introduction of First Two Speakers
Don Boesch, University of Maryland

9:00 a.m. Environmental Monitoring Lessons from NEON: Opportunities for the Gulf of Mexico
Russ Lea, NEON

9:30 a.m. Valuing Ecosystem Services for Coastal Protection And Restoration: Progress and Challenges
Ed Barbier, University of Wyoming

10:00 a.m. Discussion/Q&A

10:30 a.m. Break

10:45 a.m. PANEL 1:
Questions for panelists:
1) What are the environmental monitoring needs for developing ecosystem services models that in turn can inform habitat restoration?
2) What opportunities for innovation and long-term monitoring should our program consider?

7 minutes prepared comments, followed by a panel discussion:
- **Chris Shepard**, TNC
- **Pat Barnes**, BFA
- **Ruth Perry**, Shell
- **Sandra Werner**, ExxonMobil

12:15 p.m. Lunch/Guest Speaker
GCOOS Build-out Plan Update
Landry Bernard, GCOOS

1:30 p.m. PANEL 2:
Questions for panelists:
1) What are the environmental monitoring needs for developing ecosystem services models that in turn can inform habitat restoration?
2) What opportunities for innovation and long-term monitoring should our program consider?

7 minutes prepared comments, followed by a panel discussion
- **Becky Allee**, NOAA
- **Jon Porthouse**, NFWF
- **Chuanmin Hu**, USF
- **Nancy Rabalais**, LUMCON

2:30 p.m. Break

2:45 p.m. BREAKOUT SESSION 1
Context and Goals
1) In addition to the monitoring needs and opportunities for innovation identified by the panelists, are there other important ones that were not mentioned?
2) Building on the ideas and opportunities identified, what are the appropriate mechanisms for addressing those needs and opportunities?
3) What other entities, if any, are already addressing or attempting to address those needs? Are there opportunities for potential partnerships?

1: Moderator: **Kerry St. Pé**/Rapporteur: **Evonne Tang**
2: Moderator: **Bob Carney**/Rapporteur: **LeighAnne Olsen**
3: Moderator: **LaDon Swann**/Rapporteur: **Kim Waddell**
4: Moderator: **Cort Cooper**/Rapporteur: **Chris Elfring**

4:15 p.m. Reports from Breakout Groups (10 minutes each) and Group Discussion
1: Rapporteur: **Evonne Tang**, GRP
2: Rapporteur: **LeighAnne Olsen**, GRP
3: Rapporteur: **Kim Waddell**, GRP
4: Rapporteur: **Chris Elfring**, GRP

5:15 p.m. Closing Comments; Meeting Adjourns for Day 1

5:45 p.m. Reception

THURSDAY, SEPTEMBER 4, 2014

Vieux Carre Room—Rooftop

8:00 a.m. Breakfast

8:30 a.m. Welcome

8:35 a.m. Opening Comments: Overview of Day 2 Theme and Introduction of Speakers
Robert Carney, LSU

8:50 a.m. Planning for Environmental Impacts in the Deep Sea: A Case Study of Deep-Sea Mining
Cindy Van Dover, Duke University

9:35 a.m. Oil Industry priorities for Environmental Monitoring: Opportunities for Partnerships
Cortis Cooper, Chevron

10:05 a.m. Break

10:20 a.m. PANEL 3
Questions for panelists:
1) What do we need to understand of the physical and biological attributes of the deep Gulf of Mexico to enhance environmental protection from the impacts of oil exploration in the deep and ultra-deep water?
2) What opportunities for innovation and long-term monitoring should our program consider?

7 minutes prepared comments, followed by a panel discussion
- **David Yoskowitz**, TAMU-CC/NOAA
- **Mark Benfield**, LSU
- **Pat Roscigno**, BOEM
- **Antonio Mannino**, NASA

11:50 a.m. Lunch/Guest Speaker
Gulf of Mexico Data Management Infrastructure Needs and Challenges, **Russ Beard**, NOAA

1:15 p.m. BREAKOUT SESSION 2
Context and Goals:
1) In addition to the monitoring needs and opportunities for innovation identified by the panelists, are there other important ones that were not mentioned?
2) Building on the ideas and opportunities identified, what are the appropriate mechanisms for addressing those needs and opportunities?
3) What other entities, if any, are already addressing or attempting to address those needs? Are there opportunities for potential partnerships?

1: Moderator: **Kerry St. Pe**/Rapporteur: **Evonne Tang**
2: Moderator: **Bob Carney**/Rapporteur: **LeighAnne Olsen**
3: Moderator: **LaDon Swann**/Rapporteur: **Kim Waddell**
4: Moderator: **Cort Cooper**/Rapporteur: **Chris Elfring**

2:45 p.m. Break

3:00 p.m. Reports from Breakout Groups (10 minutes each) and Group Discussion
1: Rapporteur: **Evonne Tang**, GRP
2: Rapporteur: **LeighAnne Olsen**, GRP
3: Rapporteur: **Kim Waddell**, GRP
4: Rapporteur: **Chris Elfring**, GRP

4:00 p.m. Closing Comments
Kim Waddell, Gulf Research Program
Kerry St. Pé, Gulf Research Program Advisory Group

4:15 p.m. Meeting Adjourns

B

Speaker Biographies

REBECCA "BECKY" ALLEE is a Fisheries Biologist and Senior Scientist for the National Oceanic and Atmospheric Administration's (NOAA) Gulf Coast Services Center (GCSC) and is currently serving as the lead for NOAA's RESTORE Act Science Program science plan development team. As the lead for this team, Dr. Allee is facilitating a group of NOAA experts to develop a long-term science plan for the RESTORE Act Science Program's focus areas and priority research topics. As Senior Scientist for GCSC, Dr. Allee provides guidance and technical support to help identify priority objectives of ecosystem assessment and characterization and provides technical and scientific consultation and guidance on proposed activities for coastal resource management. Dr. Allee has been with NOAA since receiving her doctorate in biological sciences from the University of Arkansas.

EDWARD BARBIER is the John S. Bugas Professor of Economics, Department of Economics and Finance, University of Wyoming. His main expertise is natural resource and development economics as well as the interface between economics and ecology. He has served as a consultant and policy analyst for a variety of national, international and non-governmental agencies, including many UN organizations, the OECD and the World Bank. Professor Barbier is on the editorial boards of several leading economics and natural science journals, and he appears in the 4th edition of *Who's Who in Economics*. In 2008, he was named by Cambridge University as one of the 50 most influential thinkers on sustainability in the world, and among his honors and awards, he has received the 1991 Mazzotti Prize (Italy) for contributions to economics and ecology. Professor Barbier has authored over 200 peer-reviewed journal articles and book chapters, written or edited 21 books, and published in popular journals and media. His books include Blueprint for a Green Economy (with David Pearce and Anil Markandya, 1989), *Natural Resources and Economic Development* (2005), *A Global Green New Deal* (2010), *Scarcity and Frontiers: How Economies Have Developed Through Natural Resource Exploitation* (2011), *Capitalizing on Nature: Ecosystems as Natural Assets* (2011) and *A New Blueprint for a Green Economy* (with Anil Markandya, 2012).

PATRICK BARNES is a professional geologist and environmental justice advocate. In 1994 he founded BFA Environmental a minority owned, multidiscipline environmental engineering and scientific consulting firm. At their peak BFA had over 150 employees in the gulf, executing 20 million dollars in contracts. BFA has completed emergency response and environmental restoration projects in Florida, Louisiana, and Texas. At the core of a successful restoration project is data collection and monitoring. Under contracts with the South Florida Water Management District, charged with implementing the multibillion Everglades Restoration Program, BFA has provided over 3 million dollars of data collection and environmental monitoring services. In 2006 he provided $300,000 of seed capital to establish Limitless Vistas, a workforce development non-profit and Conservation Corps, which has subsequently trained and certified over 350 at-risk young adults for the emergency response and coastal restoration projects resulting from hurricanes Katrina, Rita, Gustav and Ike and the BP oil spill. BFA/LVI is currently under contract with the State of Florida's Career Source Program to provide short term environmental, geotechnical, construction inspection services to 180 unemployed and underemployed individuals in central Florida. In April of 2013 Mr. Barnes was recognized by the White House as a Champion of Change for his effort to bring environmental resiliency to vulnerable coastal communities through job training.

RUSSELL BEARD is the Director of the National Oceanic and Atmospheric Administration's (NOAA) National Coastal Data Development Center (NCDDC), a division of the National Oceanographic Data Center, Stennis Space Center, MS. He is currently serving as the Acting Director of the NOAA RESTORE Science Program. Mr. Beard was the National Environmental Satellite Data and Information Services (NESDIS) representative to NOAA's Gulf Coast Ecosystem Restoration Task Force, serves as the NESDIS representative to the Northern Gulf Institute serving on the Advisory Council, and is the NESDIS lead for the Gulf of Mexico Alliance (GOMA) Ecosystem Integrated Assessments Priority Issue Team; serves as the NOAA Regional Team Lead for the Gulf of Mexico Regional Collaboration Team

(GoMRCT), and was a GoMRCT science lead for DEEPWATER HORIZON (DWH), and a member of the DWH Joint Analysis Group. Professional highlights include serving as a senior scientist aboard the NR-1, the US Navy's nuclear research submersible; receiving the US Navy's Meritorious Civilian Service Medal and the Department of Commerce (NOAA) Silver Medal for Meritorious Service. He graduated from Millsaps College with a BA in History (1975), a BS in Geology (1984), awarded a MS degree from the University of Southern Mississippi in Geology (1986), and was a doctoral student at Old Dominion University's Department of Oceanography (1986-1987). Mr. Beard is a graduate of the U.S. Department of Agriculture Graduate School's Executive Potential Program for senior federal employees (2000). Additionally, Mr. Beard is a graduate of the University of the South (Sewanee) Extension Education for the Ministry (2005). In April of 2007, the University of Southern Mississippi, College of Science and Technology selected Russ as Alumni of the Year.

MARK BENFIELD is a biological oceanographer who is a Professor in the Department of Oceanography and Coastal Sciences at LSU. His research focuses on the use of optical, acoustical, and direct sampling systems to understand the distributions of zooplankton on scales of centimeters to kilometers. He also studies biodiversity in the Gulf of Mexico from the surface to the bathypelagic zone. This latter work is conducted through the Gulf SERPENT Project: a partnership between the oil and gas industry, the federal government, and LSU. He received his B.S. from the University of Toronto, an M.Sc. from the University of Natal, and a Ph.D. from Texas A&M University. His postdoctoral work was done in the Biology Department at the Woods Hole Oceanographic Institution where he currently has an adjunct appointment.

LANDRY BERNARD was born and raised in Louisiana. He earned a BS Degree in Physics from Loyola University in New Orleans and a MSEE Degree from Virginia Tech. Mr. Bernard has over 45 years of experience in the Marine Science Industry. His first 32 years were as a civilian in the Department of the Navy. The last 10 of those were spent serving as Technical Director of the Naval Oceanographic Office, where he managed an organization of 1000 people, a $250M annual budget, over 40 international agreements, 8 new oceanographic/hydrographic survey ships, 2 oceanographic aircraft, a high performance supercomputer center, and the worlds largest integrated data base. In 2001, Mr. Bernard began working for the University of Southern Mississippi (USM) under the Intergovernmental Personnel Act Mobility Program as an Inter-Personnel Assignment (IPA) to the National Data Buoy Center (NDBC). Mr. Bernard serves as NDBC's Program, Planning, and Integration Director and was the Project Manager for the Congressional funded Convert Weather Buoy Program. In 2013, Mr. Bernard became the Associate Executive Director, Gulf of Mexico Coastal Ocean Observing System (GCOOS). Mr. Bernard is a member of the Marine Technology Society, IEEE Computer Society, the IEEE Oceanic Engineering Society, the U.S. Hydrographic Society, the International Hydrographic Society, and the Louisiana Technology Council. Mr. Bernard is the author of over 50 papers in the area of Marine Science. In June 2001, the IOC-IHO/GEBCO approved the naming of the Landry Bernard Seamount at Lat/Long 26N177E. In 2007, Mr. Bernard was awarded a Fellow of the Marine Technology Society.

DONALD F. BOESCH is a Professor of Marine Science and President of the University of Maryland Center for Environmental Science. He also serves as Vice Chancellor for Environmental Sustainability for the University System of Maryland. Dr. Boesch is a biological oceanographer who has conducted research in coastal and continental shelf environments along the Atlantic Coast and in the Gulf of Mexico, eastern Australia and the East China Sea. He has published two books and more than 90 papers on marine benthos, estuaries, wetlands, continental shelves, oil pollution, nutrient over-enrichment, environmental assessment and monitoring and science policy. Presently his research focuses on the use of science in ecosystem management, and he is active in extending knowledge to environmental and resource management at regional, national and international levels. Dr. Boesch has served as science advisor to many state and federal agencies and regional, national and international programs, and has chaired numerous committees and scientific assessment teams that have produced reports on a wide variety of coastal environmental and climate change issues. He was a member of the National Academies Committee on America's Climate Choice and served as chair of the National Research Council's Ocean Studies Board. A native of New Orleans, Boesch received his B.S. from Tulane University and Ph.D. from the College of William & Mary. He was a Fulbright Postdoctoral Fellow at the University of Queensland and subsequently served on the faculty of the Virginia Institute of Marine Science. In 1980 he became the first Executive Director of the Louisiana Universities Marine Consortium, where he was also a Professor of Marine Science at Louisiana State University. He assumed his present position in Maryland in 1990. Dr Boesch served as a member of the President's s 7-member Oil Spill Commission, formed immediately after the Deepwater Horizon spill to investigate the root causes of the blowout.

ROBERT S. CARNEY is a Professor in Louisiana State University's Department of Oceanography and Coastal Sciences. Dr. Carney's primary research expertise is in deep-ocean biological oceanography, but he is also familiar with shallow systems having directed the Coastal Ecology Institute of LSU for 9 years. He has been awarded numerous grants for his research since 1978, including multiple awards from the Minerals Management Service (now BOEM) and National Oceanic and Atmospheric Administration to support the new sampling as well as reanalysis of archival deep Gulf of Mexico data. He was a PI in the Alfred P. Sloan Foundation Census of Marine Life and co-directs international research on continental margin ecosystems. He is a founding member of INDEEP (International Network for Scientific Investigation of the Deep Sea). In addition to basic science, he has published on the design of oil-related impact studies and information needs of deep ocean management. Dr. Carney has served on the NRC committee investigating the ecosystem services aspect of the Deepwater Horizon oil spill. In 1977 Dr. Carney earned a Ph.D. in Oceanography from Oregon State University.

CORTIS K. COOPER works for Chevron and is a Fellow, one of 25 elite scientist and engineers in the company. His primarily technical efforts at Chevron have focused on quantifying winds, waves, and currents for operation and design of offshore facilities worldwide including measuring and modeling oil spill fates; modeling hurricane alleys in the Gulf of Mexico; modeling sea level in the Caspian Sea; forecasting the Loop Current in the Gulf of Mexico; supervising major ocean current models in the Gulf of Mexico, W. Africa, NE Atlantic and NW Australia; leading a 32-company joint industry project (JIP) to improve ocean towing; leading the DeepSpill experiment, a $2 million, 24-company JIP that investigated the fate of oil and gas from deepwater blowouts; and is a leader of the API committee that is funding about $10 M of research to resolve lingering questions regarding the use of subsea dispersants. Dr. Cooper was a member of the 2003 National Research Council's Committee on Oil in the Sea, and has been heavily involved in the physical oceanography of the Gulf of Mexico for 35 years including two terms on the Board of the IOOS Regional Association. Dr. Cooper brings a wealth of relevant skills to the committee, but his grasp of industry standard operating procedure (SOP) and his understanding of oil dispersion under various oceanographic conditions will be most useful. He earned a Ph.D. in Environmental Engineering from the University of Maine in 1987, and a M.Sc. and B.S. in Civil Engineering from the Massachusetts Institute of Technology in 1977 and 1975, respectively.

CHUANMIN HU received his BS degree in physics from the University of Science and Technology of China, Hefei, China, and the PhD degree in physics (ocean optics) from the University of Miami, Coral Gables, FL, in 1997. He is currently Professsor in marine science at the University of South Florida, St. Petersburg, Florida, where he directs the Optical Oceanography Laboratory. He has been a principal or a co-principal investigator for over 20 projects funded by the U.S. NASA, NOAA, EPA, and USGS to study river plumes, red tides, water quality, benthic habitats, and connectivity of various ecosystems. He has published more than 130 peer-reviewed journal articles since 2000, many of which were highlighted on journal covers and by various organizations and agencies. His lab at USF maintains a Virtual Antenna System (VAS) and a Virtual Buoy System (VBS) to produce and share various satellite data products.

RUSS LEA is CEO of NEON, Inc. (National Ecological Observatory Network). In his capacity over the last two years he has worked with the science community and the sole sponsors, the National Science Foundation, to deliver an observatory designed to detect and enable forecasting of ecological change at continental scales over multiple decades. Dr. Lea is a professor emeritus at North Carolina State University.

ANTONIO MANNINO is a research oceanographer within the Ocean Ecology Laboratory at NASA Goddard Space Flight Center (GSFC). He was previously a Mendenhall Postdoctoral Fellow research chemist at the U.S. Geological Survey. Dr. Mannino began his career at the University of Texas (M.A. 1994) studying how environmental and ecological factors influence the spatial distribution of macrobenthos community structure. During his tenure at UT, Mannino became interested in the biogeochemistry of dissolved organic matter. At the University of Maryland (Ph.D. 2000), while investigating the chemical composition, sources and reactivity of coastal organic matter, Mannino became interested in linking the optical and chemical properties of organic matter for remote sensing applications. His current work applies field observations, satellite data and 3D coastal models to study carbon cycle processes within estuaries and continental margins. While working as a researcher at NASA since 2002, Dr. Mannino has served as project manager, laboratory manager, co-lead for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission formulation ocean science working group, MODIS ocean science team member, chief scientist and technical officer for field campaigns, science PI for engineering studies aimed at developing future ocean color satellite sensors, and mentor for four postdoctoral researchers and numerous summer interns.

RUTH PERRY is a marine scientist specializing in physical and biological oceanography, ocean observing, and policy. Dr. Perry earned a PhD in Oceanography from Texas A&M University and has 10 years of Gulf of Mexico research experience. During her time at TAMU, she focused her research on quantifying the environmental processes affecting Texas marine mammal strandings and understanding physical processes driving Texas coastal hypoxia formation, particularly how to incorporate the use of real-time ocean observing systems, remote sensing, and GIS techniques to quantify the spatiotemporal trends of Gulf environmental hazards (e.g. hypoxia, harmful algal blooms). In 2013, she joined the Gulf of Mexico Coastal Ocean Observing System and her responsibilities included incorporating GIS into ocean observing activities, including statistical mapping of environmental hazards, and on stakeholder engagement and outreach, including K-12 curriculum development. In 2014, Dr. Perry joined Shell as a Marine Science and Regulatory Policy Specialist where she supports Shell Exploration and Production offshore teams in marine science and environmental issues. Her primary role is to integrate marine science and ocean technology into regulatory policy advocacy and decision-making and her specific focus areas include Gulf of Mexico, marine sound, marine spatial planning, ocean observing, and marine mammal and life science.

JONATHAN PORTHOUSE has nearly twenty years of experience in coastal ecosystem planning, research, and management in coastal ecosystems, and is currently a Senior Manager with the National Fish and Wildlife Foundation. His responsibilities include providing technical review and oversight of projects requesting and receiving funding from the $2.5 billion Gulf Environmental Benefit Fund. He is also responsible for developing, communicating, and ensuring compliance with project monitoring requirements for the program. Mr. Porthouse previously worked for the State of Louisiana to develop basin-level assessments and restoration plans for the State's vanishing coast, including the Louisiana Coastal Area Ecosystem Restoration Program (an authorized $2 billion partnership with the Army Corps of Engineers) and the State's first Comprehensive Master Plan for hurricane protection and coastal restoration. He also spent six years as a consultant working on coastal ecosystem restoration projects and programs in Louisiana, California, and the Caribbean. He has extensive expertise in multi-objective environmental planning, adaptive management planning, development of science-based decision support systems, program development, and project management. Jon earned his B.S. in Biology from the State University of New York, Stony Brook in 1993 and earned his M.S. in Marine Science from the University of South Carolina, Columbia in 1996.

NANCY RABALAIS is Executive Director and Professor of the Louisiana Universities Marine Consortium in Chauvin, Louisiana. Since the mid-1980s, Dr. Rabalais has been studying the dynamics of the large hypoxic region in the Gulf of Mexico, which receives excess nutrients from the Mississippi River. This work includes shipboard monitoring on a large geographic scale and more spatially restricted but more often on two transects, and reliance on other monitoring by the U.S. Army Corps of Engineers and the U.S. Geological Survey. Since 1989 the hypoxia program has been deploying oxygen sensors, and now has one real-time oxygen monitoring station in coastal waters. She also deployed similar meters in the Barataria Bay estuary, LA. Other routine monitoring, but less frequent now, is for phytoplankton taxonomy and abundance. LUMCON maintains an environmental monitoring system of two stations in Terrebonne Bay, LA. Dr. Rabalais is also the Principal Investigator for the Coastal Waters Consortium, a GoMRI-funded research program. She has served on numerous committees of the National Research Council for the Ocean Studies Board and the Water Science and Technology Board.

PASQUALE "PAT" ROSCIGNO is the Chief of the Office of Environmental Studies for the Gulf of Mexico OCS Region for BOEM. Dr. Roscigno is responsible for managing the Region's Environmental Studies Program and has over 25 years of experience in managing multi-disciplinary environmental projects. Previously, he held several different research and program management positions with the BOEM and with the Department of Interior's U.S. Fish and Wildlife Service. He attended Fordham University in New York City.

CHRISTINE SHEPARD is Director of Science for The Nature Conservancy's Gulf of Mexico Program. Dr. Shepard's primary research focuses on assessing coastal hazards risk, quantifying the role ecosystems play in reducing risk, and identifying where ecosystem based approaches such as conservation or restoration are likely to be effective for risk reduction. In addition, she works to develop innovative spatial analyses and community engagement tools to help decision makers address coastal risks from climate change and coastal hazards like storms and sea-level rise. She co-authored the 2012 World Risk Report in partnership with United Nations University and was a member of the Department of Interior's Strategic Science Working Group "Operational Group Sandy" deployed to assist the Hurricane Sandy Rebuilding Task Force. She completed her Ph.D. in Ocean Science at the University of California-Santa Cruz in 2010 and her B.S. in Zoology and Psychology at the University of Florida in 2002.

KERRY ST. PÉ is the Executive Director of the Barataria-Terrebonne National Estuary Program (BTNEP), a nationally recognized effort dedicated to preserving and restoring the 4.2 million-acre area between the Mississippi and Atchafalaya Rivers in Southeast, Louisiana. Mr. St. Pé grew up near the mouth of the Mississippi River in Port Sulphur, Louisiana during the '50s and '60s where the vast coastal marshes surrounding his home inspired him to become a marine biologist. Mr. St. Pé worked for 23 years as a field biologist and regional coordinator for the Water Pollution Control Division of the Louisiana Departments of Wildlife and Fisheries and Environmental Quality. His work allowed him frequent encounters with the people, marshes, and swamps of the area now known as the Barataria-Terrebonne National Estuary. Under the Water Pollution Control Division, he investigated water pollution incidents and conducted studies of shell dredging and other environmental impacts in Lakes Maurepas and Pontchartrain as well as a major study on the impacts of oilfield brine in coastal La. His oilfield brine study was an important catalyst in getting both state and federal regulations established to stop these discharges to Louisiana water bodies. Mr. St. Pé has directed hundreds of oil spill removal and remediation events in the coastal marshes of southeast Louisiana and has developed nationally-used training courses on diagnosing causes of fish mortalities. His wetland restoration work has been featured in the best-selling book *Bayou Farewell, the Rich Life and Tragic Death of Louisiana's Cajun Coast* by Mike Tidwell and in the PBS documentary, Washing Away: Losing Louisiana and the LPB documentary, Turning the Tide. Mr. St. Pé has also received several Outstanding Publication Awards from the Louisiana Wildlife Biologists Association and has twice been awarded (1996, 2006) the Annual Coastal Stewardship Award from the Coalition to Restore Coastal Louisiana. Mr. St. Pé was appointed as the Interim Administrator of the Louisiana Universities Marine Consortium (LUMCON) from July 2002 to June 2005. Mr. St. Pé was awarded the Gulf Guardian Award in 2009 in the Individual Category by the EPA Gulf of Mexico Program. In May of 2010, he was awarded an Honorary Doctorate of Science by Nicholls State University.

LADON SWANN is Director of the Mississippi-Alabama Sea Grant Consortium (MASGC), and Director of the Auburn University's Marine Programs. He received BS and MS from Tennessee Technological University and a Ph.D. from Purdue University. Dr. Swann is responsible for implementing practical solutions to coastal issues through competitive research, graduate student training, and extension and outreach and K-12 education in Alabama and Mississippi. He also has over 26 years of experience designing, delivering and evaluating engagement programs addressing local, regional and national needs. He is actively involved in regional engagement through the NOAA Gulf of Mexico Regional Collaboration Team, multiple Gulf of Mexico Alliance priority issues teams. During 2010 and 2011 Dr. Swann served on the Oil Spill Recovery Commissions for Alabama and Mississippi, Gulf Coast Ecosystem Restoration Task Force, and served as a primary point of contact for NOAA's engagement efforts. In 2012 Dr. Swann served on the Mississippi 'Go Coast 2020' oil spill recovery planning effort. Dr. Swann is a member of the Ocean Research Advisory Council and the 2013-2104 President of the National Sea Grant Association. He also served as President of the U.S. Aquaculture Association.

CINDY LEE VAN DOVER is a deep-sea biologist with an interest in the ecology of chemosynthetic ecosystems and deep-sea conservation and environmental management. Dr. Van Dover's current research focuses on deep-ocean exploration, the study of gene flow and connectivity of deep-sea organisms, deep-sea conservation and environmental management, and, most recently, exploring new models for deep-ocean research through telepresence, distributed research teams of early career scientists, and social media. She has published more than 100 articles in peer-reviewed journals and is an active participant and Chief Scientist in NSF- and NOAA-sponsored field programs to hydrothermal vents and other chemosynthetic environments. Dr. Van Dover was a Fulbright Scholar in France and is a Fellow of the American Association for the Advancement of Science. She is currently the Harvey W Smith Professor of Biological Oceanography in the Division of Marine Science and Conservation of the Nicholas School of the Environment, Duke University, where she serves as Chair of the Division and Director of the Marine Laboratory.

KIM WADDELL is a senior program officer with the National Academies' new Gulf Research Program, after serving 3 years as a study director with the Ocean Studies Board at the same institution in Washington, DC. His recently completed reports include "An Ecosystem Services Approach to Assessing the Impacts of the *Deepwater Horizon* Oil Spill in the Gulf of Mexico" and "Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States." Kim rejoined the National Academies in 2011 after a 6-year hiatus during which he was a research associate professor at the University of the Virgin Islands and Texas A&M University working to build marine and environmental research capacity in the Caribbean region. He received his Ph.D in the Biological Sciences from the University of South Carolina and his B.A. in Environmental Studies from the University of California, Santa Cruz.

SANDRA WERNER received her Ph.D. from the Joint Program in Oceanography/Applied Ocean Science and Engineering, Massachusetts Institute of Technology/Woods Hole Oceanographic Institution, Cambridge/Woods Hole, Massachusetts in 1999. Since 2001, she has worked for ExxonMobil Corporation as a Senior Research Scientist and Environmental and Regulatory Advisor. Her areas of expertise include ecosystem services, ecosystem-based management, environmental monitoring, physical oceanography, sediment transport, marine ecological indicators, deepwater and coastal ocean processes.

DAVID YOSKOWITZ is currently Chief Economist for NOAA and is on leave as the Endowed Chair for Socio-Economics at the Harte Research Institute (HRI) at Texas A&M University-Corpus Christi. His work is focused on elucidating the link between environmental well-being and human well-being and moving practice into policy. Currently he is leading an effort to inventory and value ecosystem services for the Gulf of Mexico region and quantifying the impact of sea-level rise on coastal community resiliency. His work has taken him through much of North and Central America including Cuba, Nicaragua, Belize, El Salvador, and Mexico. He led the effort to produce *Gulf 360º: State of the Gulf of Mexico*, which was a successful collaboration between governmental, academic, non-governmental organizations, and industry in both the United States and Mexico. Dr. Yoskowitz served on the National Research Council Committee on the Effects of the Deepwater Horizon Mississippi Canyon-252 Oil Spill on Ecosystem Services in the Gulf of Mexico. He currently sits on the Socio-Economic Scientific and Statistical Committee for the Gulf of Mexico Fishery Management Council.

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Attendees' Roster

Rebecca Allee
U.S. National Oceanic and Atmospheric Administration

Alexis Baldera
Ocean Conservancy

Edward Barbier
University of Wyoming

Patrick Barnes
BFA Environmental Consultants

Russ Beard
U.S. National Oceanic and Atmospheric Administration

Mark Benfield
Louisiana State University

Landry Bernard
Gulf Coast Ocean Observing System

Donald Boesch
University of Maryland

Tommie "TJ" Broussard
U.S. Bureau of Safety and Environmental Enforcement

Robert Carney
Louisiana State University

Eric Chassignet
Florida State University

Cortis Cooper
Chevron Corporation

Chris Elfring
National Academies

Monty Graham
University of Southern Mississippi

Rebecca Green
U.S. Bureau of Ocean Energy Management

Judy Haner
The Nature Conservancy

Chuanmin Hu
University of South Florida

Robbie Kröger
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LeighAnne Olsen
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Larry Langebrake
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Russ Lea
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Antonio Mannino
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Robert Moorhead
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Lydia Olander
Duke University

John Porthouse
National Fish and Wildlife Foundation

Ruth Perry
Shell Upstream Americas

Jennifer Pettit
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