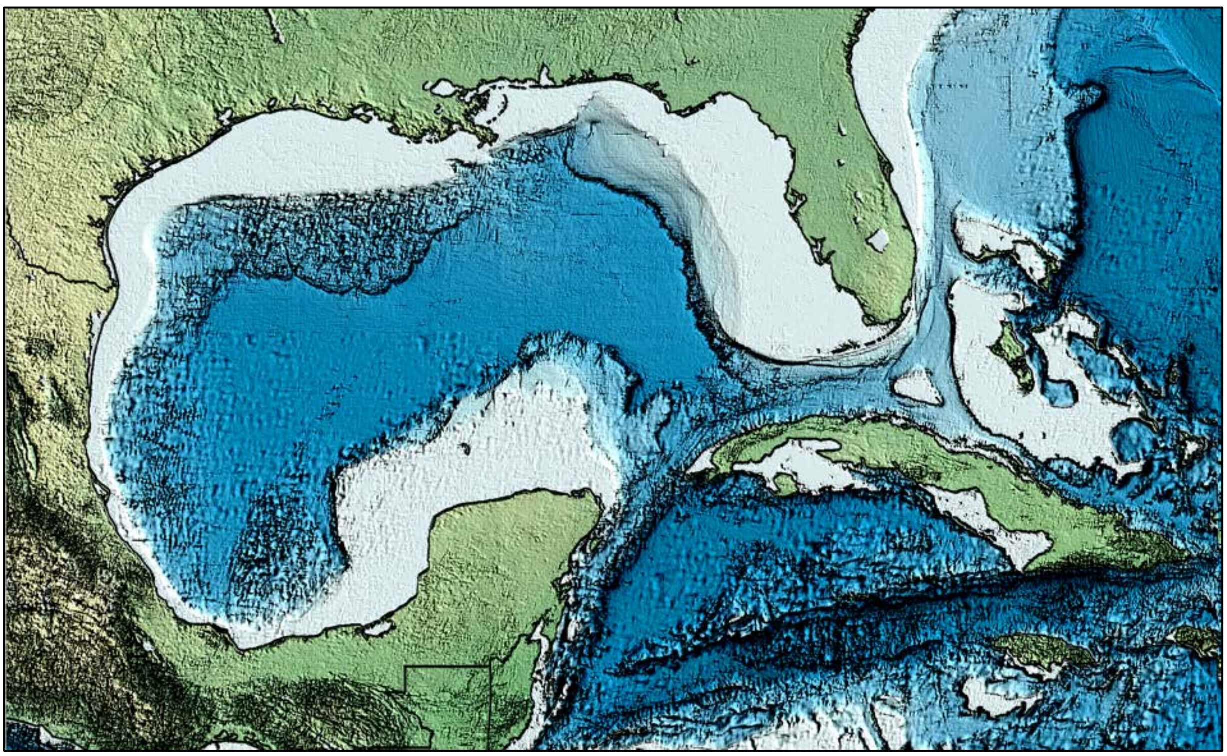
OCS Study
BOEM 2019-045

Proceedings: The Gulf of Mexico Workshop on International Research, March 29–30, 2017, Houston, Texas



U.S. Department of the Interior
Bureau of Ocean Energy Management
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Editors

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ABOUT THE COVER

The cover image was based on a topo-bathymetric rendering from the 2014 General Bathymetric Chart of the Oceans Hillshade Map Service hosted by NOAA/NCEI. The data is copyrighted to the General Bathymetric Chart of the Oceans (GEBCO), NOAA National Centers for Environmental Information (NCEI), and Natural Earth. The image was subsequently manipulated in a bitmap editing program to produce the texturized effect. Produced by M. Besonen.

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List of Abbreviations and Acronyms

ADCP	Acoustic Doppler Current Profiler
AOML	NOAA Atlantic Oceanographic and Meteorological Laboratory
ASEA	Agencia de Seguridad, Energía y Ambiente
BOEM	Bureau of Ocean Energy Management
CGOM	Coastal Gulf of Mexico
CICESE	Centro de Investigación Científica y de Educación Superior de Ensenada
CIGOM	Consorcio de Investigación del Golfo de México
CIIMAR-GOMC	Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe
C-IMAGE	Center for the Integrated Modeling and Analysis of the Gulf Ecosystem
CIM-UH	Centro de Investigaciones Marinas de la Universidad de La Habana
CINVESTAV	Centro de Investigación y de Estudios Avanzados
CIP	Centro de Investigaciones Pesqueras
CITMA	Ministerio de Ciencia, Tecnología y Medio Ambiente
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad
CONACYT	Consejo Nacional de Ciencia y Tecnología
CONAGUA	Comisión Nacional de Agua
DGOMB	Deep Gulf of Mexico Benthic Program
DWH	*Deepwater Horizon*
EcoQO	Ecosystem Quality Objective
ECOSUR	El Colegio de la Frontera Sur, Chetumal, México
ESID	EcoSpatial Information Database
EEZ	Exclusive Economic Zone
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GEF	Global Environment Facility
GERG	Geochemical Environmental Research Group
GOM	Gulf of Mexico
GOMA	Gulf of Mexico Alliance
GOM-LME	Gulf of Mexico Large Marine Ecosystem
GOMRI	Gulf of Mexico Research Initiative
GOMWIR	Gulf of Mexico Workshop on International Research
HRI	Harte Research Institute
HYCOM	HYbrid Coordinate Ocean Model
ICML	Instituto de Ciencias del Mar y Limnología (Estación de Investigaciones Marinas el Carmen)
IMT	Instituto Mexicano del Transporte
IMTA	Instituto Mexicano de Tecnología del Agua
INAPESCA	Instituto Nacional de Pesca
INECC	Instituto Nacional de Ecología y Cambio Climático
INSMET	Instituto de Meteorología de Cuba
IOC	Intergovernmental Oceanographic Commission
IPN	Instituto Politécnico Nacional
LaTex	Louisiana-Texas
LC	Loop Current

LME	Large marine ecosystem
LMR	Living marine resources
MINAL	Ministerio de la Industria Alimentaria (Ministry of Food Industry)
MPA	Marine Protected Area
NASEM-GRP	National Academy of Sciences, Engineering and Medicine, Gulf Research Program
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
NSF	National Science Foundation
OCS	Outer Continental Shelf
PAH	Polycyclic aromatic hydrocarbon
PEMEX	Petróleos Mexicanos
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SAP	Strategic Action Programme
SEFSC	NOAA Southeast Fisheries Science Center
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales
SGD	Subterranean Groundwater Discharge
SGOM	Southern Gulf of Mexico
TAMU	Texas A&M University
TAMUCC	Texas A&M University–Corpus Christi
TDA	Transboundary Diagnostic Analysis
UABC	Universidad Autónoma de Baja California
UAT	Universidad Autónoma de Tamaulipas
UJAT	Universidad Juárez Autónoma de Tabasco
UNAM	Universidad Nacional Autónoma de México
US	United States
USGS	United States Geological Survey
UV	Universidad Veracruzana

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Finally, we thank the Bureau of Ocean Energy Management (Department of the Interior), the Gulf Research Program at the National Academy of Sciences, Engineering and Medicine, and NOAA for their wisdom in seeing the need for an international workshop focused on the southern Gulf of Mexico, and, of course, for the financial and logistical support that made it possible. In particular, we thank Becky Allee (NOAA), Chris Elfring (NASEM-GRP), and Rebecca Green (BOEM), and for their efforts with the pre-event phone conferences and discussions that were critical for organizing and planning the event, and ensuring its success. We also thank Rebecca Green for the detailed reviews she provided for draft versions of the Proceedings—they greatly helped to improve the quality.

1 PART I: PLENARY PAPERS AND INVITED CONTRIBUTIONS

1.1 Preface

L. McKinney

Harte Research Institute for Gulf of Mexico Studies

1.1.1 Gulf of Mexico Workshop on International Research (GOMWIR) Plenary

The plenary session of the Gulf of Mexico Workshop on International Research (GOMWIR) was intended to lay a foundation for the working sessions to follow. Plenary speakers with recognized expertise in the Gulf of Mexico (GOM) oceanographic and marine science studies were asked to assess the current state of knowledge, identify research gaps, and provide their perspectives on research priorities for the southern GOM. All invited plenary speakers had extensive and relatively current experience in working collaboratively with international partners. The plenary session was organized into four panels, and lunch panels were held on both days of the workshop.

The Sponsors Panel provided the opportunity for sponsoring organizations to inform workshop participants about workshop goals and expectations from their specific perspectives. Presenters included:

Dr. Larry McKinney: Executive Director Harte Research Institute (HRI), Texas A&M University–Corpus Christi (TAMUCC)

Dr. Rebecca Green: Senior Oceanographer, Environmental Studies Program, Bureau of Ocean Energy Management (BOEM)

Chris Elfring: Executive Director, National Academies of Sciences, Engineering, and Medicine, Gulf Research Program (NASEM-GRP)

Dr. Rebecca J. Allee: Senior Scientist, Office for Coastal Management –Gulf Region, National Oceanic and Atmospheric Administration (NOAA)

Each of the sponsoring organizations characterized their interest in and connections with international coastal and marine science in the southern GOM. All sponsors recognized the growing interest in cooperative science between the three Gulf countries (United States, Mexico, Cuba) and stated their desire to facilitate coordinated efforts to better understand the Gulf of Mexico as a whole. Sponsoring institutions recognized that oil and gas development and joint research efforts between the United States and Mexico to address that issue was a focal point for the workshop but also expressed understanding that many issues would benefit from the combined efforts of all Gulf countries. Oil and gas development by the United States, Mexico, and Cuba presented unique challenges and opportunities that GOMWIR could help address and provide a strong foundation for the future.

The Inventory and Assessment of the Southern Gulf Panel was a report out from the pre-workshop efforts to assess what we currently know about that area of the Gulf. The HRI team was led by Dr. Mark Besonen, Dr. Kim Withers, and Dr. Gerardo Gold Bouchot. International team members included Dr. Adolfo Gracia Gasca and León Felipe González Morales of the Universidad Nacional Autónoma de México (UNAM, Mexico City); Dr. Victor Manuel Vidal Martínez and Daniel Aguirre Ayala of the Centro de Investigación y de Estudios Avanzados (CINVESTAV; Mérida, Yucatán); Dr. Sharon Herzka and Mónica Cecilia Mozqueda Torres of the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE, Ensenada, Baja California); and, Dr. Eustorgio Meza Conde and

Sergio Gabriel Jiménez of the Universidad Autónoma de Tamaulipas (UAT, Tampico, Tamaulipas). Dr. Nuno Simoes of UNAM–Sisal, prepared a biodiversity assessment of the southern Gulf with a special focus on Campeche Bank. Panel presentations included:

Overview of Pre-Workshop Inventory: Dr. Mark Besonen (HRI)

Overview of Pre-Workshop Literature Assessment: Dr. Kim Withers

(TAMUCC) Overview of Fates and Effects Database: Dr. Gerardo Gold

Bouchot (TAMU)

Meta-Database of Marine Research in Mexico: Juliano Palacios-Abrantes (University of British Columbia)

A Biodiversity Gap Analysis of the Southern Gulf of Mexico: Dr. Nuno Simoes (UNAM)

A significant challenge for GOMWIR was the relatively short timeframe given for the more than 165 participants to come together and accomplish all that was hoped for in the original planning. To help assure success of the face-to-face meeting, considerable work was done in advance of the GOMWIR workshop to provide context and to accelerate the work of the participants. It was a complex undertaking over a very short period of time, but it accomplished the initial goal of providing a focus for the workshop and illuminating gaps in our knowledge and the challenges of international data and information exchange.

The National Perspectives on the State of International Science in the Gulf of Mexico Panel was moderated by Dr. Chuck Wilson Chief Scientist of the Gulf of Mexico Research Initiative (GOMRI). Scientific program leaders from around the GOM were asked to summarize institutional activities in the GOM and their perspectives on research priorities. Panel presentations included:

Status of Marine Research in Mexico: Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe (CIIMAR-GOMC): Dr. Porfirio Álvarez, Secretario General de CIIMAR-GOMC

State of Oceanographic Research in Mexico: Consorcio de Investigación del Golfo de México (CIGOM): Dr. Juan Carlos Herguera, Principal Investigator

The State of Marine and Oceanographic Research in Cuba: Dr. Silvia Patricia González Díaz, Director, Centro de Investigaciones Marinas (CIM) de la Universidad de La Habana

The State of International Science in the Gulf of Mexico: Topical Perspectives Panel, also moderated by Dr. Chuck Wilson, included scientific leaders from around the GOM. Panel members were identified that could address the primary thematic areas of GOMWIR: Baseline Studies, Fates and Effects Studies, and Environmental Monitoring. They were asked to summarize what we know, what we don't know, and what we most need to know about the GOM from their unique areas of expertise and experience. The panel was structured to reflect the thematic focal areas of the workshop. Panel presentations included:

Perspective on International Research in the Gulf of Mexico: Dr. Elva Escobar Briones, Director Instituto de Ciencias del Mar y Limnología (UNAM)

Perspective on Environmental Monitoring Needs in the Gulf of Mexico: Dr. Tony Knap, Director of the Geochemical and Environmental Research Group (GERG) and holder of the James R. Whatley Chair in Geosciences at TAMU

Perspective on Baseline Study Needs in the Gulf of Mexico: Dr. Steve Murawski, University of South Florida, Peter R. Betzer Endowed Chair and Director of GOMRI's C-IMAGE Consortium

Perspective on Fate and Effects Study Needs in the Gulf of Mexico: Dr. Gerardo Gold Bouchot, TAMU, Department of Oceanography

Perspective on Socioeconomic Study Needs in the Gulf of Mexico: Dr. David Yoskowitz, Associate Director of HRI and Endowed Chair for Socioeconomics, TAMUCC

Two Special Lunch Panels about international perspectives on cooperative research were organized by BOEM and NOAA. The BOEM lunch panel was moderated by Timothy McCune (International Relations specialist, BOEM), and the speakers included Michael Celata (BOEM Regional Director for the Gulf of Mexico) and Alejandro Carabias (Head of the Regulations and Legal Standards Unit, Agencia de Seguridad, Energía y Ambiente [ASEA]). The NOAA lunch panel provided an overview of the GOM Large Marine Ecosystem (LME) Project with speakers Dr. Becky Allee (NOAA), Dr. Bonnie Ponwith (Director, NOAA Southeast Fisheries Science Center), and Javier Warman Diamant (Director General of Planning and Evaluation, Secretaría de Medio Ambiente y Recursos Naturales [SEMARNAT]). Both panels provided succinct summaries of regulatory-related research needs and continuing efforts to build international coordination and cooperation between governmental agencies in their respective countries. These lunch presentations were very helpful to workshop participants as they proceeded with assigned tasks to identify priorities and gaps.

1.1.1.1 Plenary Summary

The plenary session provided a framework around which the remainder of the workshop was structured. Both the national perspective panel and the topical panel provided workshop participants with information with which many were not familiar. All presenters provided Microsoft© PowerPoint© presentations which are available by searching the HRI website.

It was clear from the presentations discussing the state of research in Mexico that both coastal and ocean observations are a priority and are advancing rapidly. The CIGOM presentation by Dr. Herguera was especially informative, providing an excellent insight into the impressive scale of Mexico's national effort to better understand the Gulf and the technical expertise on which that effort is based. The presentation by Dr. Álvarez updated the workshop on the well-organized efforts of CIIMAR-GOMC to unite coastal Gulf states in Mexico to work towards a better understanding of the coastal margins of Mexico and integrate their efforts with those of the United States. Dr. Patricia González Díaz of CIM at the University of Havana provided a detailed overview of Cuban marine science, which was not well known to the majority of workshop participants. Cuban marine and ocean sciences have capacity limitations but are technically on par with other nations in the region.

Dr. Escobar's topical perspective captured the impressive, recent history of Mexican oceanographic work across several topical areas and also provided an insightful perspective on areas where the workshop should focus to best identify both gaps and priorities. Dr. Knap put GOM oceanographic research into context with efforts around the world. His special focus was on long-term monitoring gaps and priorities, which was especially illuminating for the physical sciences. Dr. Murawski has successfully led oceanographic expeditions in both Mexican and Cuban waters. His insights on data sharing and Gulf- wide baseline data needs and challenges provided a strong foundation for workshop discussions. Dr. Bouchot focused on fate and effects study needs for the southern Gulf and did so across a broad spectrum. He provided a detailed assessment of both gaps and priorities. An often-overlooked area of research in this area is socioeconomic assessment. Dr. Yoskowitz provided insights to making connections between biophysical disciplines and the broader community to evaluate the impact of investment rather than the return on investment regarding the environmental challenges of economic development in the southern Gulf.

The plenary sessions were designed to inform workshop participants as they pursued their assigned tasks. The sponsors' panel provided context as to why GOMWIR was conceived and executed. The inventory panel provided workshop participants with an assessment of what was known and available to researchers at the time of the workshop. The national perspectives panel provided a broad view of coastal and ocean sciences in all three Gulf countries, and the topical panel was focused on the three thematic areas for the workshop: baseline studies, fates and effects studies, and environmental monitoring.

GOMWIR organizers and sponsors were fortunate to have leading Gulf scientists in all of these areas contribute to the plenary session and set the stage for a lively and engaged workshop. The proceedings benefited from plenary speakers' summary contributions. All researchers with an interest in the GOM will benefit from the contributions of GOMWIR's plenary speakers and for that, the organizers and sponsors wish to thank them for their time and effort.

1.2 Plenary Papers

1.2.1 Introduction

L. McKinney

Harte Research Institute for Gulf of Mexico Studies, Texas A&M University–Corpus Christi

International coordination of environmental science initiatives between the United States and Mexico is a high priority for GOM stakeholders. As the scientific and regulatory communities work together to ensure the safe and responsible use of offshore resources, including oil and gas reserves, joint environmental research on priority issues will be essential. The dynamic nature of the GOM is such that it will take the combined efforts of all nations bordering the world's ninth largest water body to address priority research issues fundamental to a better understanding of its ecosystem functioning and the interaction of the oceanic and coastal waters of the Gulf.

Continuing and escalating challenges to the health and productivity of the GOM are threats to our national security, economy, and environmental health. The GOM is of great strategic importance to the United States. As illustrated in "Gulf 360: State of the Gulf of Mexico" (Yoskowitz et al. 2013), the United States, Mexico, and Cuba are integrally linked through demographic, economic, and ecological commonalities. The GOM is often called the "working Gulf" and for good reason. No other coastal waters are more important to the nation's energy security and overall economic health (Yoskowitz 2009). The Gulf economy generates $230 billion in economic activity each year. If this region was a country, it would be the twenty-ninth largest economy in the world (Felder and Camp 2009). The Gulf is foundational to our energy security, accounting for 54% of US crude oil and 52% of US natural gas production, with 47% of US refining capacity found along the margins of the GOM (NOS 2011). Twelve of this country's twenty largest ports are in the Gulf (NDC 2017).

It can also be called the "living Gulf" because it is, essentially, the nation's fish market, yielding 1.5 billion pounds of seafood annually (NMFS 2016). The Gulf also accounts for 44% of all US recreational fishing, providing a $16.2 billion a year economic boost to the region (SA 2013). The Gulf has about 40% of the wetlands in the nation, and most, if not all, of the nation's seagrass and mangrove habitats (Felder and Camp 2009). It is home to over 15,419 species from all five kingdoms of life, making it one of the most biodiverse seas in the world (Felder and Camp 2009).

There are numerous threats to the health and productivity of the Gulf that would benefit from international attention. Harmful algal blooms (NOAA 2016), oil spills (Robertson 2010), invasive species (Showalter 2003), sea-level rise (Davis 2011), and overfishing (NOS 2011) lead the list of environmental concerns common to all Gulf countries. There are also numerous opportunities for the three Gulf countries to work together to assure that ongoing and future economic development of shared or adjacent ocean resources proceeds with appropriate environmental considerations and coordinated resource management. An ecologically- and economically-sustainable GOM is possible when we can agree on science-driven solutions to the problems we face.

The GOMWIR brought together leading research entities and scientists from the United States and Mexico, along with peers from Cuba, under the organizing guidance of the BOEM. In addition to BOEM, the NASEM-GRP, NOAA, GOMRI, and the Gulf of Mexico Alliance (GOMA) joined HRI in organizing and funding GOMWIR. Thanks to the combined efforts of the organizing sponsors, more than 165 of the Gulf's leading coastal and marine scientists came together as part of the "State of the Gulf Summit" held in Houston, Texas the last week of March 2017. This was the largest international gathering of scientists ever to focus on the southern GOM with a common objective to discuss the current state of science throughout the Gulf LME, across a range of disciplines, and to develop recommendations for future binational research partnerships with relevance to offshore energy activities.

1.2.1.1 Background and/or Relevance of GOMWIR to BOEM Issues

International coordination of environmental science initiatives between the United States and Mexico is a high priority especially given the changes in Mexican policy concerning oil and gas development in that country. For the first time in more than a half century, private investment is allowed in the Mexican oil and gas sector of the economy. As the scientific and regulatory communities in both countries work together to ensure the safe and responsible use of offshore oil and gas resources, opportunities for joint scientific studies of the environment (e.g., monitoring) will be necessary. These developments will transcend international boundaries to help ensure that decision-making is informed by the best available science from an ecosystem-based, basinwide perspective. Moving forward, broader information exchange is required for joint science needs across a range of environmental and social science disciplines to advance coordination on offshore energy management in the GOM.

1.2.1.2 GOMWIR Objectives and Goals

GOMWIR was designed to gather information on the GOM LME with specific focus on the southern Gulf. BOEM has a long-standing research program, the Environmental Studies Program, to help inform the regulation and management of oil and gas development on the US Outer Continental Shelf (OCS), including the northern GOM. This information is extensive and widely available. An important objective of GOMWIR is to do the same for the southern Gulf and eventually all of the GOM where resource development, especially oil and gas, could be well informed through joint international efforts. Other federal resource agencies, like NOAA, also recognize the benefit of increased knowledge of the southern GOM in meeting both their domestic and international responsibilities. Research and management organizations like the NASEM-GRP, GOMRI, and GOMA have broad charters that necessitate regarding the Gulf as an LME transcending international borders. Academic organizations and institutions, like the Gulf of Mexico University Research Collaborative (GOMURC) and HRI, also have missions of broad international scope for the Gulf.

GOMWIR was organized around an initial workshop to include leading scientists from the three Gulf countries to develop collaborative research addressing Gulf-wide issues from an LME perspective.

The information generated by GOMWIR is of value to the federal agencies charged with regulating and managing resources in their respective jurisdictions. The United States and Mexican states bordering the Gulf will also benefit from this effort as will the scientific community. GOMWIR has helped to improve understanding of the current state of international environmental science related to ocean stewardship of the GOM LME and will help researchers and others to develop a roadmap to address critical information gaps through joint research. BOEM specifically benefits from this information as it works to minimize the adverse impacts from offshore energy development activities in the Gulf and to fill information gaps through its Environmental Studies Program as a result of international coordination.

The goals of GOMWIR were:

1. To develop an inventory of GOM LME research in international waters that can be used to inform interested stakeholders about current state of science across disciplines with relevance to ocean energy management needs and to provide a foundational database for an international workshop.
2. To review extant research and related programs and identify knowledge gaps for future research opportunities in the GOM across a range of disciplines.
3. To synthesize information gained through the inventory and workshop in a proceedings document to provide recommendations for high-priority international environmental science needs in the GOM and inform future research to inform resource management and regulatory needs.
4. To establish an international network of research-oriented organizations and institutions with a focus on the GOM to facilitate collaborative research which addresses priority international research in the GOM as identified by GOMWIR.

1.2.1.3 GOMWIR Design and Structure

HRI assembled an international team of scientists from the United States, Mexico, and Cuba to assure overall success of GOMWIR in achieving the stated objectives and accomplishing its goals.

The GOMWIR Inventory is focused on GOM LME research in international waters and designed to inform the current state of the science across disciplines with specific relevance to ocean energy management needs. The inventory includes the following elements:

- An annotated bibliography of peer-reviewed literature, reports, and other publications of Mexican origin that address one or more of the thematic areas and relate to international waters of the GOM.
- An annotated listing of Mexican research programs that address one or more of the thematic areas in international waters of the GOM.
- An annotated listing of Mexican data sources that address one or more of the thematic areas in international waters of the GOM.

The GOMWIR Workshop was held March 29–30, 2017 in Houston, Texas following the “State of the Gulf Summit” (March 26–28). Several of the activities scheduled for the summit were key to informing the workshop. The workshop provided the opportunity for interactions between participants, many representing active research programs, to identify knowledge gaps key to informing future research opportunities in the GOM. About 165 scientists from the United States, Mexico, and Cuba with expertise from a broad range of disciplines participated in the workshop. Participation was by invitation only with a target of 20–60 attendees in each of three thematic areas for a maximum of 180 workshop participants.

Assuring a diverse mix of expertise and experience was a focus of workshop planning. All participants were screened to have one or more of the following attributes:

- International research experience in Mexico and the GOM
- Experience or expertise in nearshore systems: GOM
- Experience or expertise in deep-water systems: GOM
- Experience or expertise in socioeconomic aspects related to the GOM
- Particular knowledge or experience in one or more of the thematic areas

GOMWIR was organized around three thematic areas, which are of specific interest to BOEM's Environmental Studies Program:

Baseline Studies that generate data that describe existing conditions and define a starting point to monitor trends of potentially impacted resources and civil society.

Fates and Effects Studies that evaluate the physical, chemical and biological processes that affect or are affected by the impacts of oil and gas activities, spilled oil, and oil dispersants, as well as the societal impacts of energy development.

Environmental Monitoring that generates data timeseries to assess effects of industry activities, and to determine effectiveness of mitigation measures contained within stipulations and conditions of permit approval for activities for offshore energy leases.

Topics of interest addressed during the workshop broadly included marine mammals and protected species, habitat and ecology, physical oceanography, water and air quality, and social science and economics, with consideration given to appropriate observational, laboratory, and modeling methods. A priority was identification of interdisciplinary approaches that integrate perspectives across disciplines and encourage or help facilitate ecosystem-based understanding and management approaches.

The GOMWIR Proceedings was designed to synthesize information gained through the inventory and workshop to provide recommendations for high-priority international environmental science needs in the GOM to inform research planning and studies development plans.

The GOMWIR Network will establish an international network of researchers and institutions that will facilitate collaborations and encourage joint efforts between academic and non-governmental science- based organizations to address priority research questions identified by GOMWIR and its proceedings. The GOMURC, CIIMAR-GOMC, CIGOM, and the RESTORE Centers of Excellence will help provide the foundation for this network, along with other institutions that are interested in contributing or have previously contributed to GOM international research.

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1.2.2 The Gulf of Mexico Large Marine Ecosystem: Background and Strategic Action Program Implementation

M. A. Navarrete and C. Susan

1.2.2.1 Summary

The *Transboundary Diagnostic Analysis of the Gulf of Mexico Large Marine Ecosystem* (TDA) was developed with scientists, experts, managers, and stakeholders, recognizing the high importance and commitment towards a healthy and productive GOM LME. It determined the baseline for transboundary priority issues in the Gulf region and serves as the basis for the immediate and long-term actions needed to modify sectoral policies, activities, and investments included in the Strategic Action Programme (SAP).

The TDA is a scientific and technical fact-finding analysis used to scale the relative importance of sources, causes, and impacts of transboundary water problems. It should be an objective assessment and not a negotiated document. To make the analysis more effective and sustainable it should include a governance analysis that considers the local institutional, legal, and policy environment.

The TDA was developed under four key points: 1) fact-finding, 2) prioritization, 3) participation, and 4) consensus, that jointly act as a diagnostic tool for measuring the effectiveness of the SAP implementation.

The SAP is a policy document negotiated by the governments of the United States and Mexico, through the coordination of the appointed Technical National Focal Points, including NOAA in the United States and the SEMARNAT in Mexico.

The SAP identifies six strategic areas to outline 71 priority actions within 21 action lines:

1. Improve water quality
2. Enhance economic vitality by avoiding depletion and recover degraded living marine resources (LMR)
3. Conserve coastal and marine ecosystems
4. Mitigate and adapt to climate change and sea-level rise
5. Improve science education and outreach
6. Cross-cutting issues

After validating the TDA and SAP the United States and Mexican governments collectively design and implement concrete actions for the protection and conservation of the GOM LME to promote shared policy goals and legal and institutional actions to address priority transboundary problems that have been previously identified by both NOAA and SEMARNAT.

To achieve the long-term objectives for the GOM LME, the SAP implementation prioritized the implementation of coordinated and integrated sustainable ecosystem-based management (EBM) approaches to address the three main transboundary challenges, and achieve the long-term Ecosystem Quality Objective (ECoQO):

- Control and reduce pollution
- Recovery of LMR
- Rehabilitation of marine and coastal ecosystems

During the second phase (2016–2021) there will be seven program executing agencies, who will collaborate to implement the activities outlined in the SAP under the supervision of scientific-technical staff from the United Nations Environment Programme (UN Environment) and with the

close collaboration of the National Programme Coordinator and the Programme Management Unit.

1.2.2.2 Background

Out of the 64 large marine ecosystems of the world, the GOM LME stands out for its unique cultural, economic, and ecological interconnectivity, and as a result for its high multisectorial economic value.

The nations bordering the GOM (Mexico, Cuba, and the United States) are increasingly aware of the threats, risks, and other relevant issues related to the management of the GOM LME, including its natural assets, socioeconomic value, and derived benefits to society, as well as their importance in the overall regional economic wealth.

Among these threats, the deterioration of coastal areas adjacent to urban centers due to pollution, oil spills, habitat loss, and unsustainable exploitation of marine and coastal natural resources stand out. Among the most outstanding consequences are an increase in algal blooms, extended low oxygen events or hypoxia, recent oil spill events, boat groundings on delicate coral reefs, and continuous oil exploration and contamination along the coast and beyond, with the respective risks of contamination threats to coastal and marine biodiversity in a basin that is highly vulnerable to storms and fluctuating climate conditions. Given that scenario, it is necessary to adopt new integrated management schemes to organize human activities in the GOM, with the objective of avoiding more serious economic and social consequences.

An apparent rise in the frequency of marked environmental changes in this ecosystem is evidenced by fluctuations in the distribution and abundance of fish such as tunas and herrings, pelagic birds (gannet and boobies), and cetaceans. This causes serious problems requiring different management levels for coastal and marine areas of the GOM LME (Duncan and Havard 1980; Pitkitch et al 2012; Roberts et al. 2016; Chen 2017).

The modular approach to LMEs is designed to link scientific assessments to states of change of coastal ecosystems, with the objective of supporting long-term sustainability and environmental quality.

The integrated EBM concept or approach seeks to ensure intergenerational sustainability of the ecosystem assets and services or processes, including hydrological and productivity cycles. This approach represents a change in paradigm and allows multisectorial interventions and a broader vision entailing an integrated ecosystem management approach that moves spatially from small to larger scales and from short-term to long-term management practices.

These efforts are geared towards intrasectorial integration in management of coastal productivity, fisheries and ecosystem contamination/health relative to socioeconomic benefits and government systems. The application of such assessments within the sphere of an ecosystem and its management is partly supported by funds from the Global Environment Facility (GEF) in collaboration with the national governments of the United States and Mexico.

GEF’s operational strategy calls for the development and implementation of projects within the International Waters (IW) Program, designed to attain global benefits. In such a context, the GOM LME is currently implemented by Mexico and the United States under a more structured approach to restore and protect the environment in international waters.

The goal of the IW Program is to give countries the necessary support to make pertinent changes in human activities carried out by different sectors and to promote sustainable maintenance of a particular body of water and the numerous basins of each country. GEF has given special priority to the change of sectorial policies and activities responsible for the most important and serious basic causes of transboundary environmental concerns.

Based on the above, Mexico and the United States started a long-term partnership in 2009 towards the integrated management of the GOM LME. The two products resulting from the first phase of this program (2009–2011), the TDA and the SAP, are the foundations for the second phase, SAP implementation, to be conducted from 2016–2021.

1.2.2.3 The Gulf of Mexico

The GOM LME is important in terms of biological productivity and includes a very high diversity of marine habitats including tropical and temperate ecosystems, estuaries, shallow inshore waters with soft bottoms, rocky bottoms and reef communities, as well as a large extension of deep sea that sustains an ample biodiversity of LMR. There are more than 300 species sustaining regional fisheries (including fishes, crustaceans, mollusks, echinoderms, and other invertebrates) in addition to LMR with unique ecosystem value in the trophic structure, such as seabirds, marine mammals, and sea turtles (Chen 2017).

Additionally, the GOM LME is a major asset to the surrounding countries, in terms of fisheries, tourism, agriculture, oil, infrastructure, trade and shipping. Commercial fishing and seafood processing are important components of the LME's economy. The infrastructure for oil and gas production in the GOM (including oil refineries, petrochemical and gas processing plants, supply and service bases for offshore oil and gas production, platform construction yards, and pipeline yards) is concentrated in the coastal regions of both the United States and Mexico. Eighty-five percent of Mexico's oil extraction isundertaken in this region, as well as 72% of US offshore petroleum production. The GOM LME contains major shipping lanes, and the volume and value of shipping and port activities has increased in the region. The tourism industry has been rapidly increasing. Approximately 55 million people live in the coastal states of the GOM, nearly 40 million in the United States and around 15 million in Mexico.

However, this high biological importance and economic productivity are at risk from a suite of anthropogenic threats.

Many stocks in the GOM are overfished or are at or near their maximum yield. Intensive fishing is considered the primary force driving biomass changes in the GOM LME. Depletion and impacts on fish stocks affects both countries given that many stocks are shared, migratory, or connected via egg or larval transport (NOAA 2016).

Habitat modification, including loss of critical habitats and connectivity, resulting from poorly planned growth in coastal and urban areas along the GOM coast, translates into a trend of urban growth at the expense of sand dunes, estuaries, marshes, seagrasses, coral reefs, mangroves, and other critical habitats.

Pollution and nutrient enrichment are important threats. The GOM is a semienclosed sea, which can aggravate pollution problems. The recent spill from the Macondo Block 252 oil well is a clear warning that more needs to be done to prevent this type of accident, but it also showed the limitations of current knowledge about the fate and effects of oil spills in the deep sea. Other industrial activities, urban wastewater, and particularly agriculture, are also important inputs of pollutants to the Gulf. All these activities introduce pollutants, such as metals (mercury is the main cause for fish consumption advisories in the United States), hydrocarbons (from the oil industry activities, but also from vehicle exhausts, industrial sources, rivers, urban runoff, etc.), pesticides from agricultural and urban use, and a recently recognized threat: emerging pollutants such as pharmaceuticals for human and veterinary use, personal care products, etc. As a relevant example, nutrient enrichment resulting from discharges in the

Mississippi River results in a "dead zone" that forms every year in the northern GoM—one of the largest hypoxic zones of water in the world.

The Gulf Coast region is also especially vulnerable to the effects of a changing climate because of its relatively flat topography, rapid rates of land subsidence, water engineering systems, extensive shoreline development, and exposure to major storms.

These growing anthropogenic threats, and their potentially widespread impacts, evidence the tight interdependencies in terms of causes and effects and an LME-wide, EBM approach is required to effectively mitigate them in the long run. However, existing management approaches are not consistent with an ecosystem-based perspective and there are currently no agreed upon binational programs for managing the GOM's resources taking into account ecosystem-based requirements. Furthermore, the two countries have institutional frameworks for coastal and marine resources protection, but no effective regional intersectoral project coordination mechanism currently exists.

The principal global benefit of the project will be an enhanced understanding of LME functions, to serve as input into LME management strategies through the TDA and SAP processes, and to establish an enabling environment and EBM practices that will contribute to the protection and maintenance of ecosystem functions and services.

1.2.2.4 GOM LME Objectives

The long-term Ecosystem Specific Quality Objectives (EcoQO) for the marine environment of the GOM LME and its social benefits are to:

> Improve water quality; enhance economic vitality by avoiding depletion and recover LMR; and conserve and restore coastal and marine ecosystems.
>
> Establish strategies and actions for the reduction and control of nutrient over enrichment, harmful algal blooms, and for the elimination of dead zones.
>
> Safeguard the habitats and community structure of the ecosystems from harmful impacts, including those caused by fisheries and pollution, that would diminish the contributions of these systems for enhancing livelihoods and human well-being.

Achieving these EcoQO will allow the GOM LME region to ensure societal benefits under a complex trans boundary scope:

> The provision of goods and services by the marine ecosystems of the GOM LME are such that they optimize the systems' contributions to societal well-being such as socioeconomic development, food security and enhanced livelihoods. The goods and services provided by the ecosystems are optimized to the region's development needs including the preservation of aesthetic, cultural, traditional, health, and scientific values of the ecosystems.

1.2.2.5 Results Phase I

1.2.2.5.1 Transboundary Diagnostic Analysis (TDA)

The TDA is a scientific and technical assessment, through which the water-related environmental issues and problems of a region are identified and quantified, their causes analyzed, and their impacts, both environmental and economic, assessed. The TDA is an objective assessment that uses the best available verified scientific and technical information to examine the state of the environment and the root causes for its degradation. The role of the TDA is to identify the relative importance of the sources and causes of transboundary water problems.

The analysis was carried out in a cross-sectoral manner, focusing on transboundary problems without ignoring national concerns and priorities. It involved the identification and prioritization of problems, their impacts (and associated uncertainties), and their causes at national, regional, and global levels, and the socioeconomic, political, and institutional context within which they occur.

The environmental impacts and socioeconomic consequences of the relevant transboundary problems were identified and indicated which elements are clearly transboundary in character like regional and/or national issues with transboundary causes (e.g., habitat destruction from urban development), transboundary issues with national causes (like point sources of pollution with ecosystem-wide impacts), national issues that are common to at least two of the countries and that require a common strategy (e.g., overexploitation of fisheries) and collective action to address issues that have transboundary elements or implications (e.g., climate change).

The objectives of the TDA for the GOM LME were to: (1) provide, on the basis of clearly established evidence, structured information relating to the scale and the relative importance of the causes and sources of the transboundary problems, and (2) identify practical preventative and remedial lines of action to ensure the sustainable integrated management of this LME, and (3) provide the technical basis for the development of an SAP.

1.2.2.5.2 Strategic Action Programme

Through the SAP, the participating countries in the GoM LME region are adopting the following long- term vision:

> A healthy and resilient GoM where coastal communities enjoy high standards of quality of life and the region's socioeconomic activities are competitive and sustainable. Likewise, the region's natural resources, biophysical structure and landscape quality provide environmental services that halt threats and reduce vulnerability of the population and infrastructure.

The GOM LME SAP (Figure 1) purpose was to identify concrete actions, individually and collectively, at the national, sub-regional and regional levels to guarantee transboundary cooperation and the integrated assessment and management of the GOM LME in keeping with the following general guidelines:

1. The concept of sustainable development should be used in a manner that guarantees the use and enjoyment by future generations of the GOM and does not compromise the health of the GOM LME ecosystems.
2. Preventive actions should start with cooperation between the two countries, taking into consideration impacts of political decisions, programs, and plans.
3. The use of clean technologies should be promoted by addressing problems related to the ecosystem, gradually replacing the technologies currently in use that generate large quantities of waste.
4. The use of economic instruments and policies to accelerate sustainable development should be promoted, such as the application of economic incentives for the use of technologies and practices that are respectful of the environment.
5. Consideration for the health of humans and ecosystems should be promoted in the main sectoral policies and development plans of the countries, especially those relating to industrial development, fishing and aquaculture, coastal development, and maritime transport.
6. Participation and cooperation of the private sector should be encouraged and considered as an integral part of the successful management and implementation of the SAP.

7. Promoting transparency, public participation and cooperation are tasks of the GoM LME that should be encouraged through wide dissemination of information to improve integrated sustainable management.

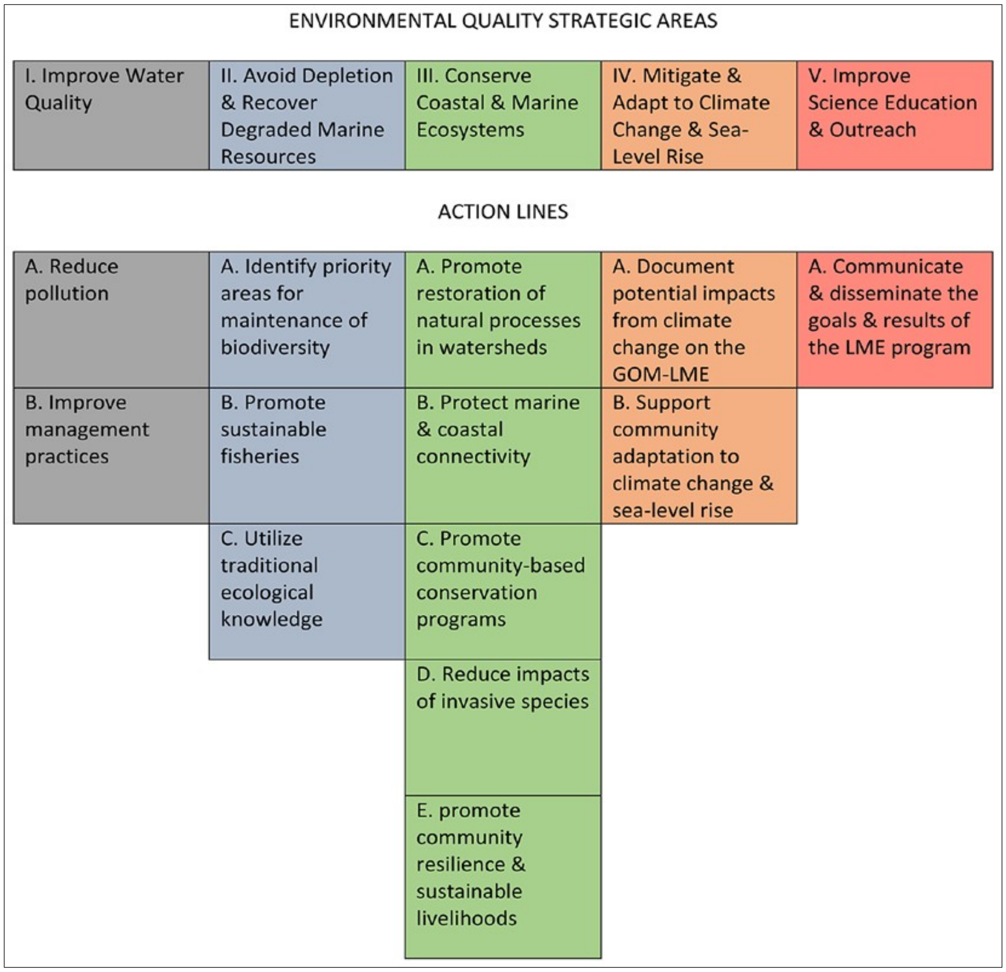

Figure 1. SAP components.

In working collectively to design and implement concrete actions for the protection and conservation of the GOM LME living marine resources, the United States and Mexico recognized the following challenges:

- Control and reduce pollution: Reduce and control nutrient overenrichment, HABs and areas of hypoxia.
- Recovery of LMR: Achieve sustainable management and use of LMR, and work towards rebuilding overfished stocks.

Rehabilitation of marine and coastal ecosystems: Conserve biodiversity and habitats in marine and coastal ecosystems through regional cooperation and development of management plans while strengthening collaborations among multiple users of marine and coastal habitats to address these challenges.

The SAP presents 71 priority actions that are necessary for the long-term vision to be achieved. In identifying the actions, both agencies recognize the importance of promoting the improvement of general social and economic welfare. All the work related to the SAP considers that the health of coastal societies and their economies are directly related to the health of coastal and marine ecosystems. It is expected that the SAP implementation will be reached through the achievement of the EcoQOs during the second phase of the project.

1.2.2.6 Next Steps

Building on the success of the GOM SAP Development Project, GEF awarded a second phase, to Mexico and the US for the development of the GOM SAP implementation project, and would have a shift of agency and would be entrusted to the United Nations Environment Program (UN Environment).

The UN Environment/GEF Project "Implementation of the Strategic Action Program of the Gulf of Mexico Large Marine Ecosystem" (GEF ID 6952; 2016-2020 – GOM SAP Implementation Project) is a five-year project specifically aimed at facilitating the implementation of the Mexico/US endorsed Transboundary Diagnostic Analysis (TDA–2011) and Strategic Action Plan (SAP–2013) for the integrated management of the GOM LME.

The project will achieve this by prioritizing the implementation of coordinated and integrated sustainable EBM approaches to address the transboundary concerns of countries bordering the GOM. Specifically, the actions proposed for the protection and conservation of the GOM LME have been designed and will be implemented to address the three main "challenges" identified by the SAP: controlling and reducing pollution, recovering LMR, and rehabilitating marine and coastal ecosystems. The SAP Environmental Quality Strategic Areas are:

- Improve water quality
- Avoid depletion and recover degraded LMR
- Conserve and restore coastal and marine ecosystems
- Mitigate and adapt to climate change and sea-level rise
- Improve science education and outreach
- Crosscutting strategic areas
- Promote compliance with existing institutional, policy and legal arrangements
- Create monitoring and evaluation indicators pursuant to GEF guidelines to measure success and progress to reach goals
- Enhance information and knowledge exchange and promote awareness and participation
- Incorporate sustainability, new technology and innovative economic instruments

The SAP's long-term EcoQO for the marine environment of the GOM is to improve water quality, enhance economic vitality by avoiding depletion and recover LMR, and conserve and restore coastal and marine ecosystems and contribute to global environmental benefits (Table 1). In particular, the EcoQO to improve water quality aims to establish strategies and actions to reduce and control nutrient enrichment, HABs, and dead zones. Its most relevant transboundary issues are: habitat alteration and/or loss; eutrophication and hypoxia; effects from hydrocarbons, pesticides, metals, emergent pollutants; and floating marine debris, especially plastics. Another EcoQO considers the safeguard of the habitats and community structure of the ecosystems from harmful impacts, including those caused by fisheries and pollution, that would diminish the contributions of these systems for enhancing livelihoods and human well-being.

Table 1. Project's target contributions to global environmental benefits

Corporate Results	Replenishment Targets	Project Target units
Maintain globally significant biodiversity and the ecosystem goods and services that it provides to society	Improved management of landscapes and seascapes covering 300 million hectares	Ha
Sustainable land management in production systems (agriculture, rangelands, and forest landscapes)	120 million hectares under sustainable land management	Ha
Promotion of collective management of transboundary water systems and implementation of the full range of policy, legal, and institutional reforms and investments contributing to sustainable use and maintenance of ecosystem services	20% of globally overexploited fisheries (by volume) moved to more sustainable levels	Percent of fisheries, by volume
Support to transformational shifts towards a low-emission and resilient	750 million tons of CO_{2e} mitigated (include both direct	metric tons
Increase in phase-out, disposal and reduction of releases of POPs, ODS, mercury and other chemicals of global concern	Disposal of 80,000 tons of POPs (PCB, obsolete pesticides)	metric tons
	Reduction of 1,000 tons of Mercury	metric tons
	Phase-out of 303.44 tons of ODP (HCFC)	ODP tons
Enhance capacity of countries to implement MEAs (multilateral environmental agreements) and mainstream into national and sub-national policy, planning financial and legal frameworks	Development and sectoral planning frameworks integrate measurable targets drawn from the MEAs in at least 10 countries	Number of Countries
	Functional environmental information systems are established to support decision-making in at least 10 countries	Number of Countries

1.2.2.6.1 Component 1: Improve Water Quality in the Papaloapan, Panuco, Grijalva- Usumacinta, and Lower Coatzacoalcos River Basins

Under Component 1, the project will deliver the following outputs:

- Output 1.1: Assess water pollution indicators and reinforce the water quality monitoring mechanisms
- Output 1.2: Strengthen the dialogue between government and industry to jointly identify pollution hot spots in the 4 river basins
- Output 1.3: Implementation of the UNIDO Transfer of Environmentally Sound Technologies (TEST) methodology in priority hot spots identified
- Output 1.4: Implementation of the Environmental Monitoring Programme (coastal conditions monitoring program and early warning system)

The outcome of Component 1 will be:

- Water quality will be improved using pollution reduction measures through an EBM approach
- Specifically, for 50 industries with the highest pollution emissions:
  - Biological oxygen demand, N, and P emissions to water bodies will be reduced by 15%
  - Industrial water consumption will be reduced by at least 10%

The Mexican Institute of Water Technology (Instituto Mexicano de Tecnología del Agua—IMTA), the National Cleaner Production Center—Tabasco Unit (NCPC-TU), the Center for Research and Advanced Studies (CINVESTAV) and the National Commission for Knowledge and Use of

Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad [CONABIO]) will be entrusted as National Executing Agencies in line with their mandates and their comparative advantages.

1.2.2.6.2 Component 2: Avoid Depletion and Recover LMR (Fish and Shellfish)

Under Component 2, the project will deliver the following outputs:

- Output 2.1: Implementation of a joint stock assessment for king mackerel (*Scomberomorus cavalla*) and spanish mackerel (*Scomberomorus maculatus*)
- Output 2.2: Use the results of the joint stock assessment for the development of new management plans for these transboundary species in Mexico and the amendment of existing management plans in the United States
- Output 2.3: Provide technical support to implement already existing management plans for red grouper (*Epinephelus morio*) and brown shrimp (*Farfantepenaeus aztecus*)
- Output 2.4: Implementation of Food and Agriculture Organization of the United Nations (FAO) Voluntary Guidelines on Small Scale Fisheries

The outcome of Component 2 will be:

- The recovery of LMR, specifically of targeted species, when compared to baseline levels, through establishment of no-take zones, effective reduction/closing of fishing season, reduction of number of fishing boats and strengthened role of women in fisheries and post-harvest activities resulting in:
  - Rebuilding of red grouper stock to at least 80% of the biomass necessary to produce maximum sustainable yield (BMSY)
  - Brown shrimp stock maintained at BMSY
- The sustainable exploitation of these species specifically with 21,000 tons of spanish mackerel caught in a sustainable manner as well as 40,000 tons of red grouper, shrimp and other fish species
- The improved management of other species achieved as a result of official agreements and cooperation mechanisms between the United States and Mexico, contributing to further recovery of LMR.

The National Fisheries Institute (Instituto Nacional de Pesca [INAPESCA]) will be entrusted as National Executing Agency with technical assistance to be provided by the FAO.

1.2.2.6.3 Component 3: Conserve and Restore the Quality of the Coastal and Marine Ecosystem through Community Involvement and Enhanced Bilateral Cooperation

Under Component 3, the project will deliver the following outputs:

- Output 3.1: Community education programs focusing on domestic wastewater and solid waste sources will be implemented
- Output 3.2: Community-based wetland restoration in selected sites will be supported
- Output 3.3: Improved coordination and bilateral cooperation will be achieved through strengthening of networks
- Output 3.4: The effectiveness of MPAs will be enhanced by linking them into networks

The outcome of Component 3 will be:

- Improved ecosystem health from reduced pollution and nutrient loads into the mangroves and wetlands, in particular:

- 30% reduction of the discharge of pollutants (waste and sewage)
- 30% decrease in the amounts of waste handled incorrectly
- Decrease in nutrient content and other pollutants resulting in a measurable reduction of contaminated mangrove areas
- Accelerated recovery of the mangroves and wetlands cover
- Significant and measurable carbon sequestration and water quality improvement
- A network of MPAs in the Gulf of Mexico to focus science, education and management at special places that are critical for the conservation of the Gulf ecosystem. MPAs are the references for the strategies used to protect the Gulf's ecosystem and manage its resources.

- In addition, habitats will be recovered for ecologically important and/or commercially important fish species, as well as for resident and migratory bird species through promotion of protection and sustainable use of natural resources from an economic, touristic and food security perspective.

The outputs under Component 3 will be delivered by the Universidad Autónoma de Yucatán and the Instituto de Ecología, A.C. as National Executing Agencies as well as by the Project Management Unit (PMU). The PMU, via the Network of MPAs, has been allied with the work done in the TDA/SAP phase with NOAA´s National Marine Sanctuaries and National Protected Areas Offices The PMU has also made a recent alliance with The Ocean Foundation and CubaMar, with the work for more than 10 years on their "Trinational Initiative" 3NI, between Mexico, US, and Cuba, putting together RedGolfo de México.

The GOM SAP implementation project will address some of the issues and challenges identified by the SAP and in so doing will seek and support targeted actions to operationalize the implementation of the endorsed SAP. This will be achieved with an investment by GEF of $12.9 million (USD) and cofinancing by Mexico and the United States amounting to $124.2 million (USD) through implementation of three "action" components, the first aimed at improving water quality, the second at recovering depleted stocks of LMR, and the third, addressing the dual challenge of conservation and restoration of the ecosystem, and one management component, aimed at supporting effective monitoring and evaluation by UN Environment, and the widest possible dissemination of results and lessons learned.

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1.2.3 Perspectives of the Mexican Consortium of Marine Research Institutes of the Gulf of Mexico and the Caribbean (CIIMAR-GOMC): Opportunities and Challenges for Regional Research Cooperation

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1.2.3.1 Abstract

The GOM LME encompasses a vast array of ecological connections. To be able to fully understand all processes with the aim to conserve its assets and for sustainable development of the region we need the expertise and input of scientists from the surrounding nations. Existing scientific programs should commit for a long term, close cooperation. The Consortium of Marine Research Institutes of the Gulf of México and Caribbean (CIIMAR-GOMC) of Mexico calls for a Regional Science Interim Commission. This Commission would serve as the appropriate space to discuss the long-term sustainability of the region, with science key to accomplishing this endeavor, and to enable cooperative programs that would improve socioeconomic conditions and resilience of coastal communities and livelihoods in the Gulf region.

1.2.3.2 Introduction

The GOM and Caribbean Sea of Mexico together represent one of the most important natural and productive regions of the three nations around the Gulf, due to the natural resources and many industries and sectors that have developed along its coasts. These are an integral part of the identities of the three nations and represent an important factor for the future development of the region. They feed the economy and help support regional development, providing jobs and opportunities, and mobilizing the user sectors of the Gulf and Caribbean.

This region provides goods and services for many sectors, but multiple challenges face this region. Pollution degrades coastal and marine habitats, reducing access to recreational sites and opportunities for trade, and threatening public health and safety. The loss of the coastal habitat impacts the stability of the marine populations, with important economic and cultural consequences. Overfishing threatens current opportunities for sustainable commercial fisheries, compromises food security, and impacts ecosystem function, reducing the possibility of stock recovery. The impacts of climate change, such as sea-level rise, increase the vulnerability of coastal communities to damage from extreme weather events such as hurricanes. In addition, these problems interact with one another, amplifying their impacts on the health of the ocean.

As coastal populations grow, there is and will be competition for space between well-established activities such as fishing, maritime transportation, military activities, and energy development, and emerging uses such as renewable energy and aquaculture. This competition creates conflicts between users and represents a challenge to decision makers. Inefficient government decision making affects the availability of economic opportunities and prevents intersectoral agreements and the necessary conservation of resources. It is very important that decisions are based on the best available scientific evidence and the informed opinions of the national research institutions established in the region.

The challenge for the three countries around the Gulf is how to use the established capabilities and opportunities to improve understanding of the oceans, seas, and coasts and their function, and how to make better use of these resources sustainably, while maintaining their health and resilience. Thus, advances in research, science, and technology, must be generated to improve understanding of the roles and services provided by the marine environment, how development alters those roles and services, and how these changes influence human activities and quality of life. Applying this knowledge will inform local management practices and help improve and maintain healthy ocean, seas, and coasts, which ultimately support job creation and new economic opportunities, allowing Mexico, Cuba and the United States to both benefit from and conserve valuable ocean resources.

Recognizing these challenges and opportunities, a central goal of existing consortia, such as the Mexican CIIMAR-GOMC, is to help solve the aforementioned challenges, building on innovative and robust science. Scientists around the Gulf recognize and emphasize the responsibility to provide information that will improve ocean and coastal resources. In addition, they also recognize the need to improve consideration of the importance of tackling these challenges not just by interested stakeholders, but by society as a whole, using common sense and solutions based on the best scientific evidence.

1.2.3.3 CIIMAR-GOMC´s background

CIIMAR-GOMC was born in 2011 within the context of the Global Environment Facility (GEF)-funded binational program of Mexico and the United States "Integrated Assessment and Management of the Gulf of Mexico Large Marine Ecosystem." This was an initiative that was also presented at the State of the Gulf Summit held in Houston Texas in December 2011. The consortium was established through a Memorandum of Agreement (MOU) signed by nine academic and research institutes based in the five coastal states of Mexico that face the GOM and/or Caribbean and the Louisiana Universities Marine Consortium (LUMCON) on December 6, 2012 in Villahermosa, Tabasco, at the Universidad Juárez Autónoma de Tabasco (UJAT).

CIIMAR-GOMC's mission is to "Integrate, organize, and enhance the efforts of scientific research institutions to generate appropriate diagnostics and propose and implement sustainable solutions to environmental, social, and economic problems of the GOM region." CIIMAR-GOMC envisions that it will be "recognized as a high-level, scientifically authoritative organization committed to strengthening sustainable development and environmental integrity of the Gulf of Mexico."

CIIMAR-GOMC promotes multidisciplinary research and facilitates its use by society, which is necessary for the transfer of knowledge. This implies that relevant fields of knowledge must be developed to address environmental and social challenges. The institutions that participate in CIIMAR-GOMC have great infrastructure and suitable human resources to face the challenges of the twenty-first century.

CIIMAR-GOMC has become a self-supporting organization that has exceeded initial expectations. It has developed its own trademark and gained the recognition at the highest levels of governmental agencies dealing with marine issues in the GOM region, as well as academic institutions around the Gulf. There are 34 national member institutes and organizations and over 100 international academic and research institutions that are primarily based in the United States, Europe, and Latin America. The consortium has strengthened communication and cooperation with local, regional, state, and federal authorities and with international organizations, and has promoted strategies based on a multidisciplinary ecosystems approach.

The future of a healthy and resilient Gulf will require a comprehensive and integrated plan that focuses on restoring functional integrity and ecosystem services. For many decades, the GOM LME has been subjected to a variety of negative impacts, for example oil spills such as the Ixtoc 1 spill (1979–1980) and more recently the *Deepwater Horizon* (DWH) oil spill (2010). In formulating this plan, scientists and decision makers in Mexico, the United States, and Cuba must understand that because of the the highly dynamic nature of the Gulf's environment, adaptive management must be instituted so that the plan is responsive to changing conditions. A bi- or tri-national or regional framework will lead to longer-term, more successful results. This is one of the added values of creating CIIMAR-GOMC.

CIIMAR-GOMC has made it possible to define priorities and strategic components needed to support scientific research and technological development in the southern GOM LME. These are vital for a better understanding of marine environment functions and their relationship with human activities. CIIMAR- GOMC provides information on the best local management practices for the valuable resources in the oceans under Mexican jurisdiction and supports the creation of new employment and economic opportunities, in addition to broadening food safety and security.

1.2.3.4 Crosscutting and International Collaboration

To enhance CIIMAR-GOMC's performance and cooperation with the northern Gulf region, Memoranda of Agreement (MOA) were signed with several US academic institutes and government organizations, including LUMCON as an initial signatory member in 2012. The Northern Gulf Institute (NGI) of Mississippi State University became a signatory member in 2013. NGI was born from the cooperation between NOAA and five additional academic institutions. NGI conducts research on four major subjects: ecosystem management, integration and visualization of geospatial data, coastal risks, and effects of weather on regional ecosystems. NGI also promotes extensive collaboration and provides an observation platform for area mapping and improving evaluation of impacts on living marine resources.

The Gulf of Mexico University Research Collaborative (GOMURC) was established in 2014 and is composed by 80 public and private universities in the United States. CIIMAR-GOMC is committed to working closely with its counterpart in the United States and this collaboration will boost scientific research on transboundary issues in the GOM due to the extensive connectivity of its geographical features.

The Gulf of Mexico Coastal Ocean Observing System (GCOOS) signed an MOA with CIIMAR in February 2015, and the two groups are working closely on several Gulf monitoring issues. The goal of the collaboration between the US Integrated Ocean Observing System (IOOS) and CIIMAR-GOMC is to develop a Mexican Integrated Coastal and Ocean Observation System (Mex-ICOOS). Another key relationship has been established with BOEM to promote bilateral workshops, and information transfer activities in the Gulf. In addition, the UN, through the UNESCO Intergovernmental Oceanographic Commission, has endorsed CIIMAR-GOMC and is supporting its work and advocacy for the sustainable management of oceans and coasts of the GOM LME.

CIIMAR-GOMC has also established a close relationship with other northern Gulf organizations like the Gulf of Mexico Alliance (GOMA), the Environment Protection Agency's (EPA) Gulf of Mexico Program, the National Aeronautics and Space Administration's (NASA) Develop Program, and HRI. These entities have attended several workshops in Mexico, and, with CIIMAR-GOMC, these organizations have participated in the biannual HRI "State of the Gulf of Mexico Summit" since 2011. A noteworthy collaboration that CIIMAR-GOMC has established that is of specific domestic and regional interest is for construction of Mex-ICOOS, a vital observatory that will produce information to help reduce risks and increase resilience of the marine and coastal environment due to climate change. This collaboration includes entities in Mexico, the United States, and Europe. CIIMAR-GOMC continues to seek opportunities to establish relationships and agreements to address the Mexico-US binational regional priorities in the GOM. With time, CIIMAR-GOMC will pursue similar agreements with Cuba and other countries of the region.

1.2.3.4.1 Examples of the Institutional Work of CIIMAR-GOMC Members

The consortium is supporting various projects through the leadership and participation of its member institutions and, in some cases, with the participation of civil society and local, state, and federal governments. Some examples are presented below.

The Universidad Juárez Autónoma de Tabasco (UJAT) has given shape, content, and cohesion to the consortium through its responsibility for coordinating, designing, conducting, guiding, and promoting its work. At the same time, the UJAT carries out its own investigations pertaining to marine and coastal resources of the region, particularly aquatic pollution and toxicology, coastal planning and organization, the development of aquaculture, and the implementation of regional public policies. The consortium coordination work demands a huge effort to build new local, domestic, and transboundary relationships and to strengthen the existing relationships, as well as to define the future research foci that align with the needs of the country. Likewise, UJAT has been the driving force in fostering the bilateral Mexico-US Forum for Higher Education and Scientific Research (FOBESII). UJAT has pushed for innovative programs to research pollution in the GOM and the Grijalva-Usumacinta Watershed via its partnership with NASA and provides support to other regional projects (e. g., tidal observation program). UJAT received the EPA's Gulf Guardian Award in 2015 in recognition of its work in building the capacity of the CIIMAR-GOMC consortium.

The Center for Research and Development of Port, Maritime, and Coastal Engineering (CIDIPORT) of the Universidad Autónoma de Tamaulipas (UAT) serves a growing demand for projects and services linked to regional (domestic and international) port sector development and for specialized studies in coastal and maritime engineering and oceanographic research using its research vessel UAT-I CIDIPORT.

The Institute of Engineering at the Universidad Nacional Autónoma de México II-UNAM, located in Sisal, Yucatán, has one of the most advanced facilities to study coastal areas. The academic unit of the institute at Sisal was created in June of 2009. It is composed of the Laboratory of Engineering and Coastal Processes (LIPC) research group. The research focus of the LIPC is the study of coastal physical processes that develop at the interface between sea, land, and air, including the open sea, continental shelves, beaches, estuaries, and semi-enclosed water bodies. The objective of the fundamental and applied research undertaken by the LIPC is to contribute to knowledge that will support both conservation and sustainable exploitation of diverse and fragile coastal environments. In particular, field experiments, physical modeling, and numerical modeling address topics such as generation and transformation of waves, propagation and transformation of tides when approaching the coast, sedimentary transport, coastal erosion, and other phenomena. The LIPC is integrated with the Faculty of Sciences and the Faculty of Chemistry research groups on the Sisal campus of UNAM which also focus on studies of the coastal zone.

The Marine Sciences and Fisheries Institute of the Universidad Veracruzana (UV) collaborates in drafting public policy proposals related to fishing and carrying out the comprehensive fisheries management studies for several commercial marine species of the GOM.

The Instituto Politécnico Nacional (IPN) supports the creation of Mex-ICOOS and has undertaken the task of convincing the relevant government bodies to carry out the operational implementation of the project. The Research Center in Applied Science and Advanced Technology-Unit Altamira of the Instituto Politécnico Nacional (IPN-CICATA-UA) has modeled waves and evaluated sea level and sea surface temperature in the GOM associated with climate change scenarios. These studies have contributed to the Tamaulipas State Program for Climate Change and the ECCO-Cities Report for the south coast of Tamaulipas funded by the Tamaulipas government and UNEP. IPN-CICATA-UA also carries out field observations of oyster reefs, waves, currents, and eutrophication studies in freshwater lagoons associated with the Tamesí River, Pánuco estuary and adjacent coastal zone, as well as providing field support for recovery/deployment/emergency missions of CICESE's Kongsberg sea gliders that study Loop Current eddies that propagate and dissipate along the Tamaulipas and northern Veracruz coastline. It is also part of the Mexican Centre for Innovation in Ocean Energy, currently conducting regional studies of potential wave energy and saline gradient energy.

The Universidad Autónoma de Baja California (UABC) created the National Center of Oceanographic Data (CENDO)**.** CENDO is a tool used to disseminate enviromental oceanographic products generated from national and/or international historical records. The UABC has implemented the Regional Coastal Oceanographic Observatory (OORCO) that provides users with realtime data and information for planning and developing marine activities. Currently UABC OORCO is committed to the implementation of the Southern Gulf Network of High Frequency Radars covering the entire Mexican coast. This project is a subcomponent of the SENER-CONACYT Gulf research project administered under the CIGOM under the leadership of CICESE based in Ensenada, Baja California.

The CONACYT research center ECOSUR, with four campuses in southern Mexico, is a center of excellence, and its Chetumal campus conducts studies in the Caribbean and GOM, some in close collaboration with NOAA, as well as institutes in Spain, and Cuba.

Universidad Autónoma de Campeche (UAC), Institute of Ecology, Fisheries, and Oceanography of the Gulf of Mexico (EPOMEX) was founded in 1990. The mission of the institute has been to promote the application of scientific knowledge to conserve the marine and coastal resources of Mexico. Through research, education, and dissemination of science, EPOMEX builds strategic alliances with different sectors to improve ecosystem function and increase biodiversity to support the well-being of future generations. The academic staff of EPOMEX partners with governmental and non-governmental organizations to contribute both to management and policy that will directly benefit society. EPOMEX offers educational opportunities at different levels (e.g., short courses, workshops, seminars, undergraduate courses), as well as its multidisciplinary master of science degree in Management of the Coastal-Marine Zone. EPOMEX also provides research grants that encourage students to relate their research to the pressing problems of society.

Instituto Mexicano del Transporte (IMT), under the Ministry of Communications and Transport (SCT), contains the Coordination of Port Engineering and Geospatial Systems (CPEGS). Its new Maritime Hydraulic Laboratory (MHL) began operating in July 2001 at IMT facilities in the State of Queretaro. CPEGS is comprised of the following workgroups: Laboratory of Marine Hydraulics, Computational Hydraulics, Hydraulic Port and Coastal Projects, Field Studies, Oceanographic Equipment Calibration Laboratory, Laboratory of Vessel Maneuver Simulations, Environmental Port Hydraulics Laboratory (in development), Instruments and Mechanisms, and Workshops. CPEGS functions include conducting applied research studies in maritime hydraulics, development of port and coastal engineering projects, and provision of related technological services to the federal, state, and municipal governments and private companies.

In 2004, the IMT began to operate the National Oceanographic and Weather Stations Network (RENEOM) to provide the Mexican maritime sector with information about oceanographic and weather conditions in Mexican ports. RENEOM consists of measuring buoys, tide gauges, and weather stations in 44 strategic locations along the Mexican coast where they measure the characteristics of waves, water surface temperature, sea level variations, and meteorological variables. Argos and GOES satellite systems are used to transmit measurements of ocean conditions, which are used mainly by Mexican port authorities and port users but are also consulted by the general public. With the RENEOM project, IMT became part of the National Tsunami Warning System of Mexico (SINAT) and has strengthened linkages with universities and research centers.

Instituto Mexicano de Tecnología del Agua, (IMTA) is a government lab focused on research and innovation of water technology. IMTA has carried out several projects in the GOM related to climate change, sea levels, hydrodynamics of coastal lagoons, numerical modeling, water quality, and meteorology. One project funded by IMTA that is currently underway is to investigate sea level and coastal erosion in the southern coastal plains of the GOM. The goal of the study is to determine vulnerability of the coastal region due to climate change and to look for evidence of land subsidence associated with exploitation of oil fields in the coastal plains of the GOM. Collaborating with IMTA on this project to understand the coastal dynamics of the southern coast of the GOM are CICESE, CICIMAR-IPN and UAM-Iztapalapa.

In the Caribbean, the Universidad de Quintana Roo (UQROO) has described reef systems, determined sediment characteristics in MPAs, carried out a trophic and ecological characterization of the Bay of Chetumal, and analyzed the population's vulnerability to extreme hydrometeorological phenomena and climate change, in addition to many other studies.

The Universidad Autónoma Metropolitana-Campus Iztapalapa (UAM-Iztapalapa) conducts research in the lagoons, and other coastal and marine areas of the GOM and Caribbean Sea related to pollutants, hydrometeorological phenomena, and hydrological and physicochemical dynamics. It has done monitoring studies of dynamic coastal processes in coastal areas of Campeche, Tabasco, and the Caribbean Sea, mainly with regard to erosion related to changes in sea level and increases in the frequencies and intensities of hurricanes.

The Southeast Global Change and Sustainability Center (CCGSS) conducts research to determine factors related to contamination, hypoxia, and eutrophication in the southern GOM and the associated Grijalva and Usumacinta River basins.

The Mérida Unit of the Interdisciplinary and Advanced Studies Center (CINVESTAV) has generated information on coastal ecosystem health by studying trophic processes in reef ecosystems, contaminants in the marine environment, and geospatial analyses of coastal areas. The Department of Marine Resources was created in 1980 with the objective of developing the main thematic axis of the Mérida Unit, study of coastal and marine ecosystems, to help guide the development of the region. Its mission is to "establish high-level human resources and carry out cutting-edge scientific and technological research to contribute to the management and rational use of the coastal ecosystems of the Gulf of Mexico and the Caribbean Sea, for the benefit of the society."

1.2.3.5 Opportunities and Challenges

During the GOMWIR workshop held in Houston, the CIIMAR-GOMC presented an initiative to create a "Gulf of Mexico Regional Interim Commission for Science." The Interim Commission would engage scientists and experts from the three nations, Cuba, Mexico and the United States, involved in any relevant research and any academic organization. The draft ideas for the Interim Commission include:

- **Strengthen national, regional, and international cooperation**
    - Strengthening existing regional alliances and building new relationships according to identified needs and priorities will contribute to the protection of the oceans, coasts, and basins associated with the GOM by supporting the science and actions needed in the face of limited resources.
    - The objective is to increase communication between the marine and coastal resource users, to facilitate alignment of goals and projects, to increase the use of existing resources for science and technological development, and to improve coordination in the region with a common

vision of the GOM.

- **Support priorities and issues of regional importance**
    - There is a need for data sharing among and between the authorities and organizations responsible for providing data on the marine environment.
    - The goal is to identify existing resources in the region so that cooperation can be expanded beyond the current organization of regional alliances and existing partnerships. This includes increasing data collection and analysis to advance regional efforts and compiling available data and scientific literature for use to meet common regional goals and to identify best management practices.
- **Involvement and engagement of local and regional communities**
    - Existing regional consortia can work with local communities in each country in the GOM and the Caribbean, to help regional and local planning groups to prioritize use of scientific methods. A focus would be on in integrating ecosystem knowledge and scientific data collected by community groups.
    - The Interim Commission would promote involvement of local communities and landowners, so that their rights would be safeguarded. In addition, the Interim Commission would work to establish agreements for appropriate management in each region of the GOM and Caribbean Sea.

The Interim Commission would work on the following issues:

- **Sustain a regional and transboundary vision**
    - Strengthen a common GOM ecosystem- based vision
    - Build actions under the ecosystem-based approach and the GOM's transboundary nature
    - Foster regional activities and enhance trinational capabilities to document the transboundary elements that sustain goods and services of the region
    - Develop mechanisms with science-based indicators to track ecosystem health and transboundary elements
- **Strengthen regional governance**
    - Promote participation of coastal states in regional activities, research programs, observing actions, database development, and data management in science-based, decision-making processes
    - Foster tri-national participation in scientific regional activities and ad hoc joint research actions
    - Strengthen education and public participation
- **Propose ad hoc bi- and trinational research actions**
    - Implement strategic research actions developed under the ecosystem-based approach using existing organizations, consortia, and academic institutes
    - Focus on appropriate research topics or foci of great interest among the three nations
    - Strength the Gulf´s regional research database and determine critical information gaps and research needs among the three nations so that research can be conducted collaboratively
    - Promote technological innovation and increase research capabilities among the three nations
    - Develop short- and long-term priority actions and needs and identify potential participants
- **Create a common ocean and coastal observing system**
    - Enhance the integrated ocean and coastal observing system for the GOM
    - Promote ad hoc ocean and coastal observing systems
    - Establish a network of existing observing assets
    - Define priority research needs and identify the observing assets needed
    - Stimulate regional cooperation and supply equipment, technology, and training as appropriate
    - **Develop a long-term trinational research program**
    - Consult with national scientists and experts to determine priority topics and issues that should be addressed in a long-term research program. Potential topics may include:

    - Harmful algal blooms
    - LMR stock assessments
    - Conservation of ecosystems and biodiversity
    - Resilience of coastal communities
    - Invasive species
    - Alternative energy resources
    - Ocean observing systems
- **Support informed decision making**
  - Promote baseline studies and complementary QA/QC data and use of standard indicators
  - Foster ad hoc joint studies, research, and monitoring
  - Translate science to support decision-making processes
  - Develop informative newsletters and use other available mechanisms to rapidly enhance science communication
  - Enhance national capabilities to create data-based information centers to support informed decision making
  - Design appropriate communications tools and mechanisms to disseminate science results that can be used to engage civil society and stakeholders at large

1.2.4 What is the Most Important Natural Resource Issue that Cuba, Mexico, and the United States, Which Border the Gulf of Mexico, Should Address Together?

A. Knap

Texas A&M University

1.2.4.1 Abstract

Repetitive and long-term time series measurements of ocean parameters provide an opportunity to monitor ocean health. Currently, there are no biogeochemical time series measurements in the deep GOM. This presentation discusses biogeochemical monitoring needs and suggests that Cuba, Mexico, and the United States work in the western and eastern gaps of international jurisdictions in the GOM to establish and maintain a long-term measurement system that uses new technologies.

1.2.4.2 Introduction

My background is in sustained observations in global ocean or ocean time-series measurements. I was privileged to be the founder of one of the major ocean observing systems of the open ocean, the Bermuda Atlantic Time-Series Station (BATS). For 30 years I was also the principal investigator of the Panulirus Hydrographic Station or "Station S" started by Henry Stommel in 1954. These stations still exist today and continue to provide data. I believe the reason that they still exist is that the quality of the data they provide is excellent, and the data are rapidly disseminated, shared, and used by a large research community, not just the principal investigators of the program. The Hawaiian Ocean Time-Series (HOT), was started by David Karl in October 1998 and is similarly successful (Karl et al. 2001). The HOT data are widely used, and there has been roughly 30 years of continuous and generous funding from the US National Science Foundation, because many Division of Ocean Sciences program managers saw the value of continuing the program. The data that have been collected from these programs is exceptional, and what we need in the GOM is a continuous measurement program of the same quality. Throughout this paper I continue to emphasize the importance of sustained observations, because every day you do not start an ocean time series is always one day too late.

I believe that you can manage only what you can measure, and this article is going to focus on the following questions:

- What do we know about the GOM?
- What do we need to know about the GOM?
- What are the impediments to understanding? What is getting in the way?
- How can Cuba, Mexico, and the United States work together to improve our knowledge of the GOM and fill the gaps?

We know a lot about the GOM, and the HRI "State of the Gulf" is an excellent compendium of current knowledge from all three countries that share the Gulf (Yoskowitz et al. 2013). Recently, another excellent study was carried out by The Ocean Conservancy: "Charting the Gulf: Analyzing the Gaps in Long-term Monitoring of the Gulf of Mexico" (Love et al. 2015). It turns out that we know a great deal about GOM ecosystems. In the United States there are literally hundreds of state and federal monitoring programs for fisheries, birds, invertebrates, marine mammals, sea turtles, nearshore sediments and associated resources, oysters, submerged vegetation, shallow and mid-water corals, shorelines, a few deep marine habitats, and the water column, but they may be patchy, intermittent, or duplicative (NASEM 2014, 2015). Continuous deepwater (>200 m) monitoring similar to that provided by BATS and HOT is lacking. Another problem is that monitoring programs for the same resources may not use the same methods and protocols, making Gulf-wide comparisons of important assets difficult or impossible (Love et al. 2015). This is true in the United States and may also be true of programs in Cuba and Mexico. We need to work together with our partners in these countries to make sure we have a holistic assessment of the GOM. Figure 2 provides a schematic of the problem—The Gulf of What? We hope that after the present meeting of GOMWIR we will be able to populate these maps with measurement systems in Mexico and Cuba. It should be noted that today, five years after the DWH oil spill, very few of the assets deployed to determine damage from the spill are still deployed. Some have said that for offshore monitoring we may not be much further ahead of monitoring the deep water of the GOM than we were prior to the spill. With billions of dollars spent on the spill and the subsequent legistlation, there are no commitments to establish a continuous, long-term, deep ocean observation systems. As I will highlight later, new and improving technologies are making these kinds of observations easier and cheaper. A commitment to long-term measurements supported by GCOOS would be a good way to start (GCOOS 2014).

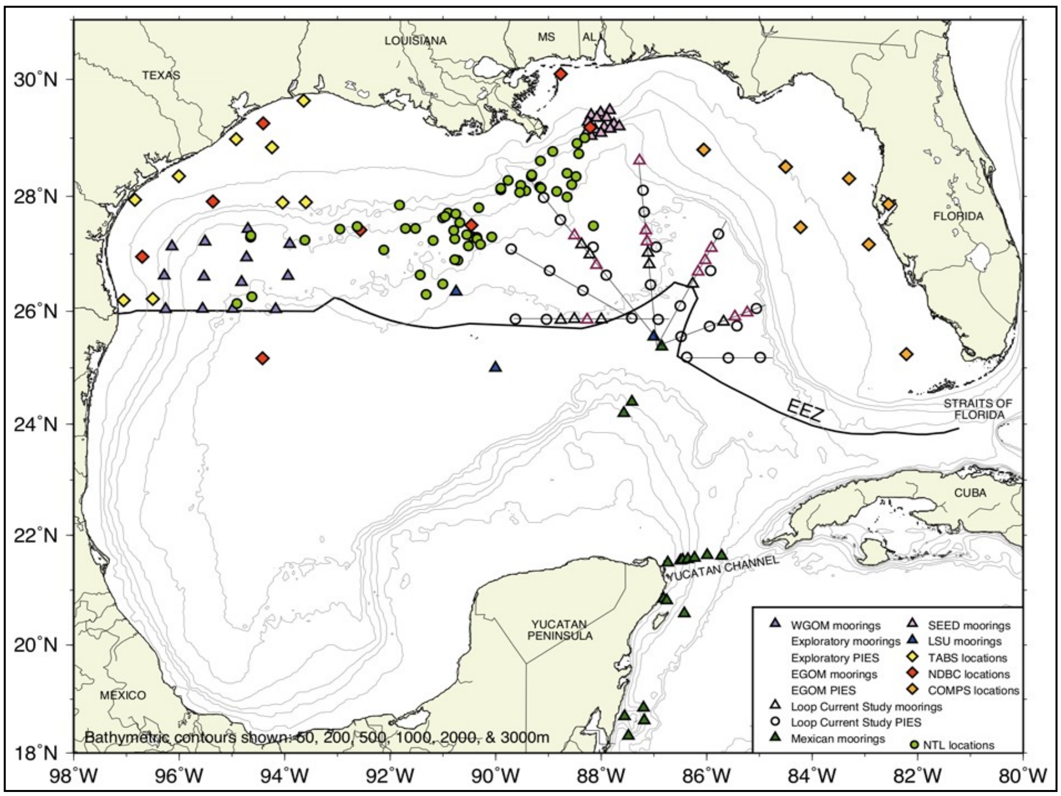

Figure 2. Map of deployed US assets in the GOM after the DWH oil spill.

Note what we know about systems in the holistic GoM. Most of these assets are no longer in place. Map courtesy of Steven DiMarco.

Perhaps one of the main drivers of change in the GOM is a natural phenomenon, the Loop Current. This is a variable current driven by the 20–30 million cubic meters of seawater, which pass through the 200 km-wide Yucatan Channel each second. This oceanographic current provides the major portion of the energy for the GOM. This current sometimes forms a well-described loop with current speeds of over 4 knots and variable direction, but at times the loop pinches off and develops a warm eddy which moves generally to the northwest and sometimes causes chaos to the offshore oil and gas business. Generally, these eddies meander for ~6–10 months and slowly dissipate off the western edge of the Texas–Mexico shelf. There are proprietary models which are used to predict these eddy-shedding events, but they are not 100% accurate. These predictions are provided to oil and gas companies and other operators in the GOM by the Naval Research Laboratory and commercial firms such as Horizon Marine that provide a subscription service. Many other studies are published on the Gulf Loop Current eddy, based on satellite data, but are not predictive (Walker et al. 2003). Recently, the NASEM-GRP established an expert panel to review what is known about the Loop Current and its eddy shedding (NASEM 2016).

1.2.4.3 Long-Term Measurement Programs in the Ocean

Over the past 30 years, ocean measurements have been structured through the Global Ocean Observing System (GOOS) managed by the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Various working groups have also been managed by IOC, for example coastal and ocean panels. IOC does not fund the measurements but expects that the participating countries will provide the funding and that institutions within those countries will carry out the work. In the United States, the Integrated Ocean Observing System (IOOS) funded by NOAA, which is divided into 13 regional alliances, including GCOOS. One of the major global coordinating groups is the Partnership for Observing the Global Ocean (POGO 2017). POGO was initiated in 1999 to coordinate groups taking ocean measurements; currently there are 38 partners including the Bigelow Laboratory for Ocean Sciences, Harbor Branch, Florida Atlantic University, Monterey Bay Aquarium Research Institute, Scripps Institution of Oceanography, TAMU, and the Woods Hole Oceanographic Institution in the United States and the Oceanology Division of CICESE in Mexico. TAMU's GERG and CICESE are the only two members that work in the GOM. POGO has promoted observations underpinning ocean and climate science, interpreted scientific results for decision-makers, provided training and technology transfer to emerging economies, and built awareness of the many challenges still ahead.

POGO, IOC, and the World Meteorogical Organization (WMO) partially fund a sustained measurement program for the global ocean called OceanSITES (Figure 3). OceanSITES is a worldwide system of long- term, open-ocean reference stations that measures dozens of variables and monitors the full depth of the ocean from air-sea interactions to the seafloor. Its network of stations or observatories measure many aspects of the ocean's surface and water column and uses, where possible, automated systems with advanced sensors and telecommunications systems with measurements often available in real time, while building a long record. Observations cover meteorology, physical oceanography, transport of water, biogeochemistry, and parameters relevant to the carbon cycle, ocean acidification, ecosystem, and geophysics. Membership in OceanSITES is free provided data are shared with WMO and made freely available. One of the glaring gaps that can be seen in Figure 3 is that there are no long-term measurement programs in the GOM other than NOAA's National Data Buoy Center (NDBC) weather buoys which are not part of OceanSITES. This needs to be rectified.

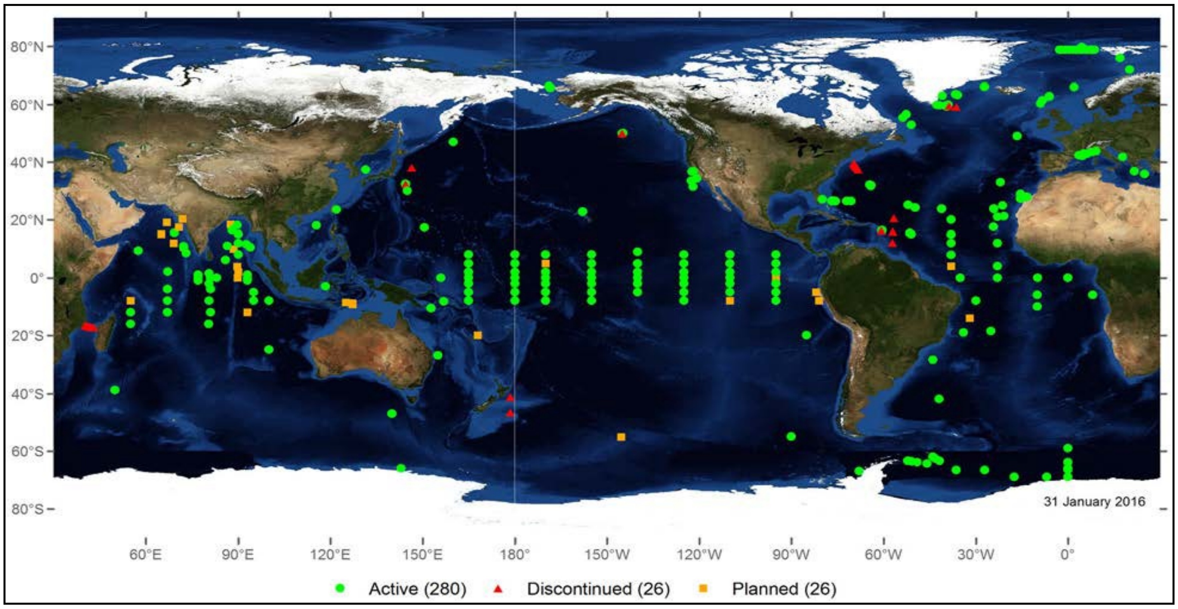

Figure 3. OceanSITES stations around the world as of January 2016.

Green dots represent active stations, red triangles are discontinued stations, and orange squares represent planned stations.

1.2.4.4 The Benefit of Long-Term, Sustained Ocean Observations

The ocean is inherently variable and the parameters that are measured to determine ocean health are also variable and change with seasons, temperature, and location. The preferred strategy to overcome this variability is to make measurements at the same place over time. For example, the 60-year temperature and salinity record of the Panulirus Station near Bermuda (Figure 4) shows an increasing trend over the years. Closer examination of these data shows a seven-year increase in temperature between 1970 and 1977 followed by a sharp decrease in temperature between 1977 and 1984. Short-term measurements in the ocean might show a completely different picture that might raise an alarm about ocean warming or cooling without the benefit of a 60-year perspective. Figure 5 shows the longest continuous record of dissolved CO_2 in the world and while it shows large interannual variability, it also shows a clearly increasing trend in the concentration of CO_2 in both the atmosphere and the water. The effects are clear with pH at the station decreasing over time indicating ocean acidification (Figure 5). This is alarming because even in the open ocean, acidification is a major concern. In addition, phytoplankton communities in the Sargasso Sea around Bermuda have changed over this same 25-year period, shifting from diatoms that make silica tests to cocolithophores to smaller phytoplankton, such as *Synechococcus*, a cyanobacterium (Lomas et al. 2012). We have no idea whether this is a natural shift or caused by changing water chemistry. This illustrates the need for a baseline, which is lacking for most parameters in the GOM!

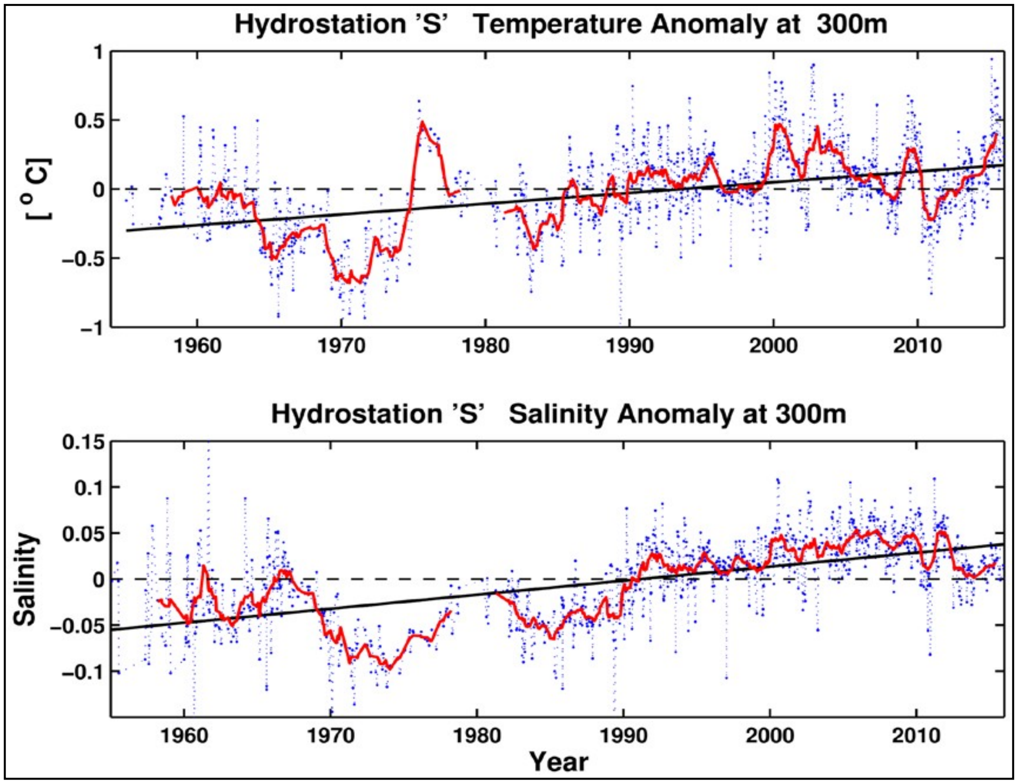

Figure 4. Panulirus Hydrostation S temperature and salinity observations from 1954 to 2010.

Note major trends. Observatory Data courtesy of Bates, Johnson and Knap (in prep).

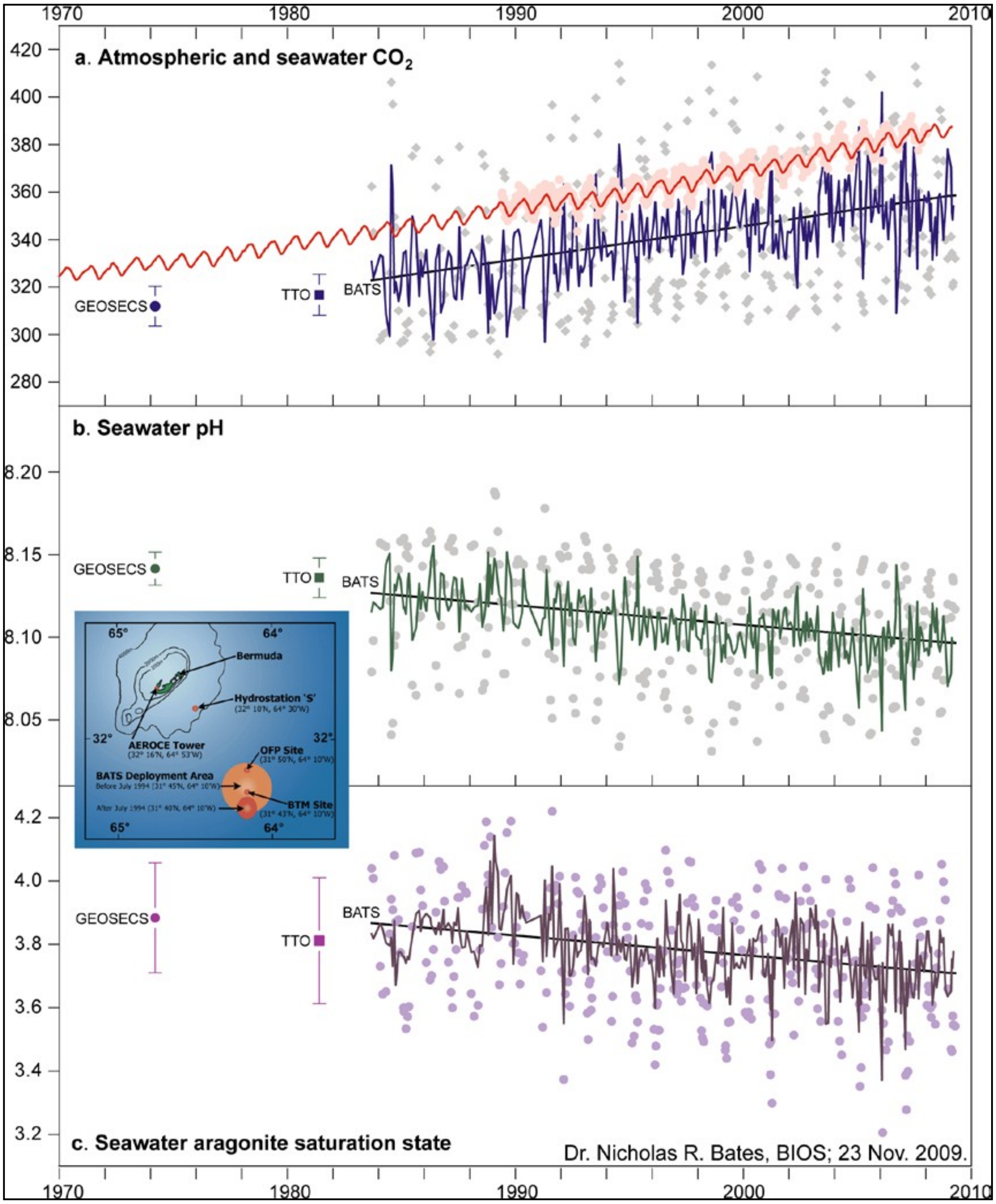

Figure 5. CO_2 and pH at BATS from 1988 to 2009.

The line in the upper panel is the Mauna Loa atmospheric CO_2. Note the variability and trend.

1.2.4.5 Gulf of Mexico

The reasons ocean conditions vary in the GOM are no different than any other area in that physical and chemical conditions are altered by processes such as riverine outflows and changes in water densities and temperatures. In the GOM, currents are dominated by the Loop Current and its eddies. Outflows from the Mississippi and Atchafalya Rivers add significant amounts of fresh water, especially in the nearshore areas, that alter temperatures, densities, and nutrient concentrations. Data such as these are crucial to the development and exploitation of the large oil and gas assets which are dependent on accurate prediction of conditions in the Gulf. When data on the deep GOM are available, they can be quite surprising. For example, Figure 6 shows variability of currents off Green Knoll during 1999–2000 (Knowlin et al. 2001). These data, collected from current meters deployed every 100 m from near the surface to almost 2,000 m,shows incredible current variability even in deep water. At the surface, an eddy named “Juggernaut” was characterized by high current velocities in the top 400 m from September–November, 1999. During the same time currents were relatively quiescent between 700 and 1,000 m, but below 1,200 m, currents were strong and variable. Later in the year, currents are also not correlated with depth. These observations make it clear that it is difficult to predict current velocities and directions with models especially since useful measurements are few and far between.

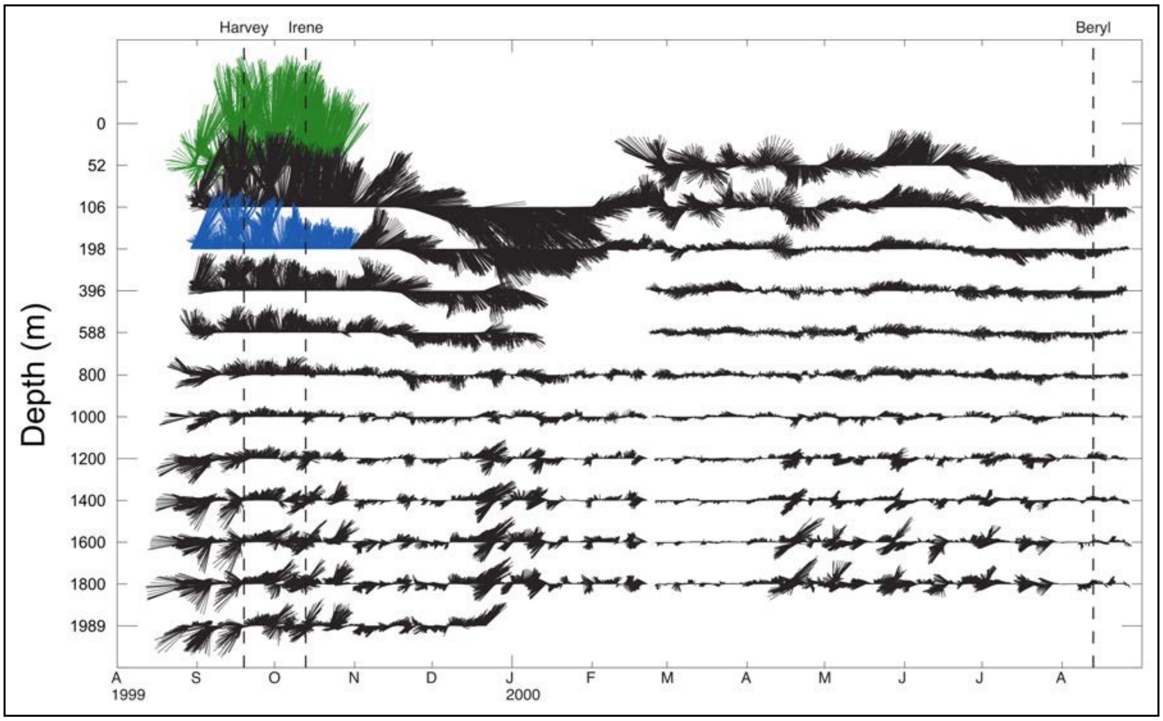

Figure 6. Current speeds at a mooring on a 1-year deployment in GOM waters over 2,000 m deep off Green Knoll (Knowlin et al. 2001).

Sentinel stations in the deepwater GOM need to be established and they must be funded for substantial amounts of time for there to be sufficient data to provide explanations and/or predictions for changing conditions in the area. Just as importantly, these stations should be shared by the three countries that surround the Gulf. The political boundaries of the GOM provide an opportunity for collaboration, because there are two areas of international waters in the area. In 1982, the UN Convention on the Law of the Sea defined a state’s (country’s) Exclusive Economic Zone (EEZ) as between the seaward limits of a state’s territorial sea and 200 nautical miles offshore. In the GOM, there are two gaps, known as the Western Gap and the Eastern Gap, that are beyond EEZs of the three countries (Figure 7). An opportunity may exist to place observing instrumentation in the eastern gap for access by Cuba, Mexico, and the United States and in the western gap by the United States and Mexico. Each country would not be required to transit through any other country’s EEZ to do research in these areas.

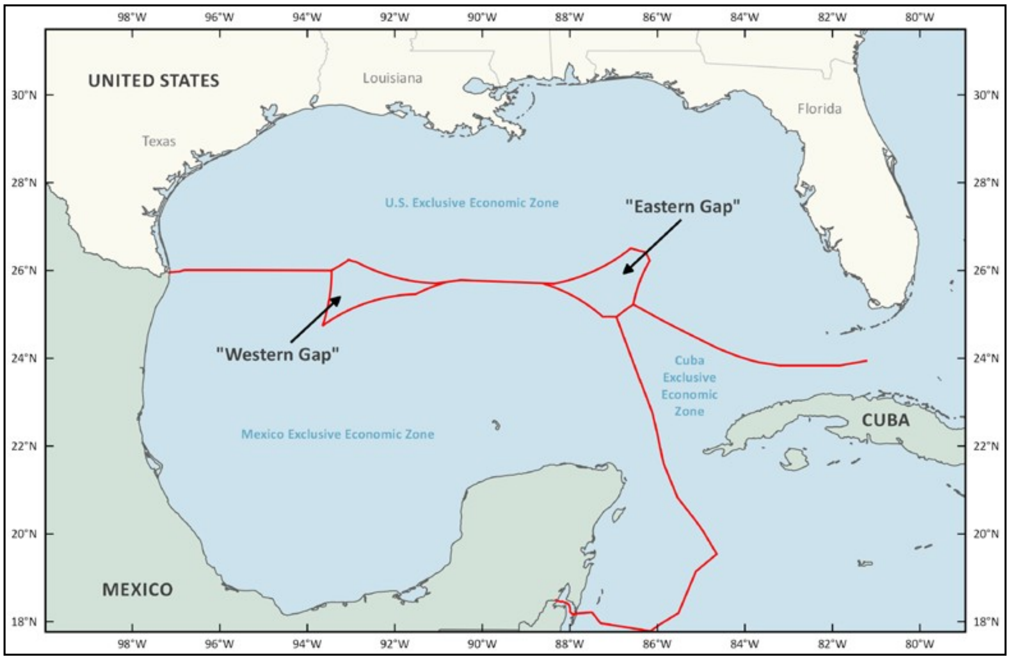

Figure 7. The geopolitical boundaries of the GOM showing the eastern and western gap in the countries' EEZs where research can be conducted.

Source: Basemap shapefiles courtesy of Natural Earth. EEZ boundaries from the Maritime Boundaries Geodatabase managed by the Flanders Marine Institute. Figure prepared by M. Besonen.

One of the main issues with sentinel stations is the cost, because they usually require a great deal of ship time and labor. Fortunately, costs are coming down with development of new technology especially remote vehicles, including remote ships, gliders, unmanned aerial vehicles (UAVs), autonomous underwater vehicles (AUVs), etc. Figure 8 shows some examples of these kinds of vehicles that are currently being used in the GOM and which are owned and operated by GERG. These vehicles require dedicated pilots and engineers, expensive batteries, sophisticated ballasting and engineering, and in most cases insurance, especially for surface vehicles which can be involved in collisions. They are not cheap to operate (about $1,000 per day), but they are much less expensive than chartering a ship. And, the resolution of data that is collected provides a granularity of information that could never be gotten with a ship-deployed rosette and CTD or a fixed mooring with a profiler. Thus, these vehicles represent a very important option to consider in planning future oceanic observations. In the case of the Ocean Observatories Initiative (OOI 2017), gliders are playing a very important role in the collection of very high resolution data including temperature, salinity (Figure 9), chlorophyll, oxygen, colored dissolved organic matter, and CO_2, among others.

Figure 8. Examples of remote Instrumentation at TAMU’s GERG.

Clockwise from top: A Teledyne buoyancy Glider (Stommel) rated for 1,000 m depth; “Bubbles”, a research sled designed and built at GERG for investigating bubble plumes in the GOM–towed 1 m off the bottom; Autonaut, a wave-powered surface vehicle owned by the Texas General Land Office and operated by GERG has an Acoustic Doppler Current Profiler (ADCP) to remotely measure currents in the water column; a Liquid Robotics wave-powered surface vehicle fitted for ocean acidification measurements at the Flower Garden Banks 180 km south of Galveston, Texas. Photos by A. Knap and S. DiMarco.

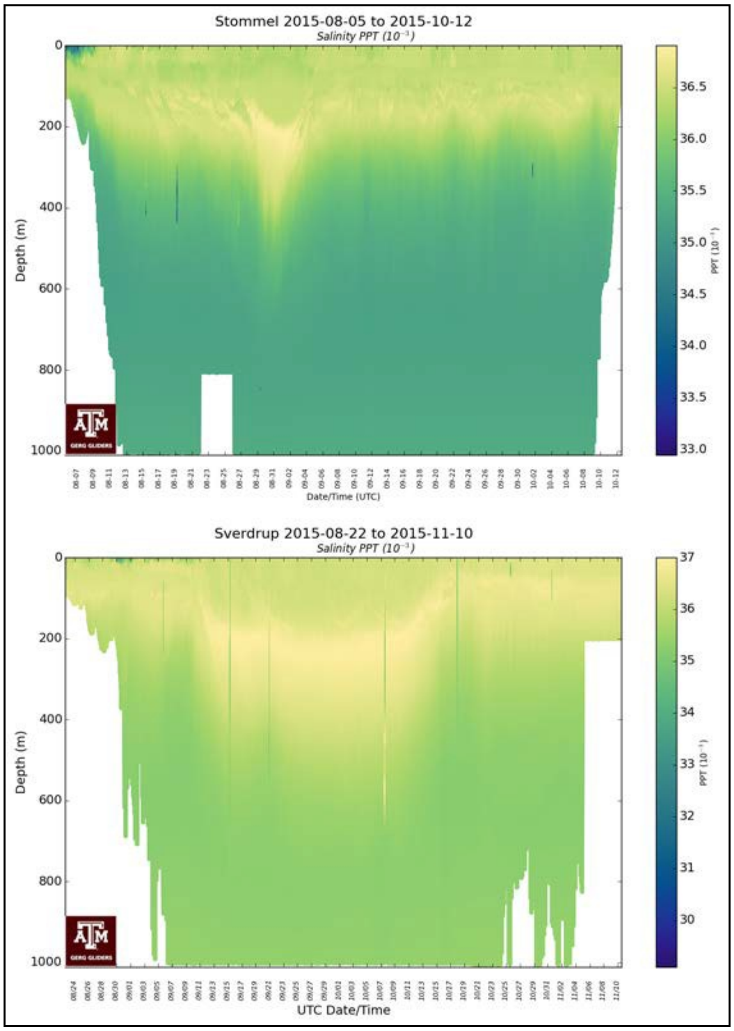

Figure 9. Example salinity data from GERG's Stommel and Sverdrup gliders.

There are also other opportunities for data collection. For example, ships transiting through the GOM ("vessels of opportunity") can be used to provide data by equipping them with various sensors colocated with the cooling intakes for the engines. These so-called "ferrybox" systems have been used in Europe and elsewhere to collect oceanographic data in real time. Improvements in the ability to determine the identity of biological species present by the sounds they make continues. Right now, marine mammals are being tracked effectively using acoustics. Collecting acoustic data at various points in the ocean may provide a better understanding of marine biodiversity as this technology continues to improve. Another tool that may increase knowledge of marine biodiversity is e-DNA (environmental DNA) to determine the species of fish that have been in a specific area. As fish swim, they shed DNA and if there is a good library of DNA fish samples for comparison, this type of data collection could be useful (Thomsen and Willerslev 2015).

1.2.4.6 Conclusion

Sustained ocean observations in the GOM are important to the three countries sharing this resource. Without them, knowledge of issues impacting the ocean will suffer, such as increasing upper ocean heat and its effect on the intensities of hurricanes, or how greater evaporation of seawater and the resulting increase in atmospheric water may increase coastal flooding. Other environmental issues that can be addressed through ocean observations, especially baseline observations, include hypoxia, harmful algal blooms, ocean acidification, and oil spills. Cuba, Mexico, and the United States should come together and establish an integrated ocean observing baseline. The shared geographical provinces known as the eastern and western gaps beyond the EEZs of the three nations are one place to start.

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1.2.5 Perspectives on Fates and Effects: Study Needs in the Southern Gulf of Mexico

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1.2.5.1 Abstract

The effects of pollutants on marine organisms and ecosystems have been well documented. However, for the northern Gulf, until the launch of the Gulf of Mexico Research Initiative (GOMRI), relatively few papers had been published on the effects of pollutants, particularly pollutants related to the oil industry, in the GOM. Papers describing studies in the southern GOM are fewer, but there is a history of studies funded by Petróleos Mexicanos (PEMEX), with oceanographic cruises each year covering most of the Mexican Gulf. Regretfully, most of that information has not been published, because it is considered proprietary. There are clearly knowledge gaps, particularly for the southern GOM. One interesting finding is that there are some differences in the approaches being used in the northern and southern Gulf to assess the impact of the oil industry.

1.2.5.2 Introduction

The effects of pollutants on marine organisms and ecosystems have been well documented. However, for the northern Gulf, before the DWH oil spill, relatively few papers were published on the effects of pollutants related to the oil industry in the GOM. Now GOMRI-funded research has resulted in many studies on the effects of petroleum, in different forms, alone or mixed with dispersants. Papers describing studies in the southern GOM are fewer, but there is a history of studies and oceanographic surveys funded by PEMEX. However, most of that information is considered proprietary. This report emphasizes studies done in the southern Gulf, but also mentions studies for the northern Gulf reported through late March 2017 in the GOMRI database.

Changes in community structure of different types of marine organisms have been used to assess the impact of pollutants, particularly in sediments. In the southern GOM, changes in free-living nematode community structure related to total hydrocarbon concentrations in sediments were reported by Gold-Bouchot and Herrera-Rodríguez (1996) in the area close to the offshore oil-producing zone. Clustering of the sampling stations was related to organic matter content and granulometry, and in three of the four cruises, total hydrocarbons in sediments also influenced clustering. Hernández-Arana et al. (2005) reported changes in the community structure of macrobenthos in sediment samples collected along four transects crossing the oil-producing zone in the southern Gulf during two cruises, one in the rainy season and the other during the winter storm season. Sampling was designed to take into account depth and changes in sediment type (terrigenous versus carbonated). A pattern of pollution was found, with pollutant concentrations increasing in the oil-producing zone. Using univariate (ANOVA) and multivariate (Bio-ENV) statistical techniques, a relationship between microbenthic fauna community structure and environmental variables and oil-industry-related variables (barium and chromium concentrations) was found. Kuk-Dzul et al. (2012) reported changes in microbenthic community structure in coastal lagoons along the northern coast of the Yucatan Peninsula. Canonical correspondence analysis showed a significant relationship of microbenthic fauna with environmental factors such as salinity and pH, but also with low molecular weight polycyclic aromatic hydrocarbons (PAHs). Brown et al. (2000) reported the effects of pollutants in sediments, and other environmental factors, as driving forces for the structure of microbenthic communities in estuaries in the northern Gulf. Different impacts of oil and dispersants on deep corals were studied by DeLeo et al. (2016), and particularly growth rates of deep corals (Prouty et al. 2016), histology (Silva et al., 2016), community structure (Fisher et al. 2014; Hsing et al. 2013; White et al. 2012) and deep corals and other benthic communities (Fisher et al. 2016).

In the case of certain groups of benthic organisms in the northern Gulf, the effects of oil on meiofauna (free-living nematodes and copepods) diversity were reported by Landers et al. (2014a), and effects of metals on meiofauna were reported by Landers et al. (2014b). Effects on salt marsh crabs (Zengel et al. 2016a), and on the effect on larval settlement and condition of blue crabs (Grey et al. 2015) have been reported, as well as effects of oil on crab transcriptome (Yednock et al. 2015). The decline of benthic foraminifera was one of the effects found after the DWH oil spill (Schwing et al. 2015). Oil and chemically-dispersed oil affected oyster larvae (Laramore et al. 2014) as well as oyster physiology (Soniat et al. 2011). The effects of oil on periwinkles were also studied (Zengel et al. 2016b).

Fish have been extensively studied after the DWH oil spill. The physiological effects of oil on mahi-mahi embryos and larvae was reported by Xu et al. (2016), and the effects on fish assemblages by Able et al. (2015) and Fodrie et al. (2011). Organismal and population responses were summarized by Fodrie et al. (2014), and external skin lesions were described by Murawski et al. (2014). Genetic response in fish exposed to oil was described as very complex by García et al. (2012). Responses in different tissues at several biological levels in killifish were reported by Dubansky et al. (2013).

Several authors report on the effects of oil and dispersants on zooplankton at different levels. Thus, photochemically-enhanced toxicity of oil to copepod nauplii was reported by Almeda et al. (2016). Long- term impacts of overfishing and pollution on plankton trophodynamics were reported by Walsh et al. (2016). Effects on ctenophores by oil and chemically-dispersed oil were reported by Parsons et al. (2015). Effects on feeding of copepods (Almeda et al. 2014a) and growth rates of barnacle nauplii (Almeda et al. 2014b) have been studied, as well toxic effects in general (Almeda et al. 2014c). Changes in community structure were studied by Carassou et al. (2014). Bioaccumulation of PAHs and its effect on survival of both adults and larvae of zooplankton (Almeda et al. 2013a) and other toxic effects on zooplankton (Almeda et al. 2013b) have been published.

Phytoplankton have received less attention. Changes in phytoplankton community structure before and after the DWH spill were reported by Parsons et al. (2015), and toxic effects on microalgae by Garr et al. (2014). A description of general impacts is given by Ozhan et al. (2014). Toxicity and mutagenicity of water from the GOM and their implication for possible impacts on resident organisms was assessed by Paul et al. (2013).

A novel approach has been to use the community structure of parasites in fish and other organisms to evaluate the impact of pollutants. The parasites and symbionts of the pink shrimp (*Farfantapenaeus duorarum*) were used in Campeche Sound, as well as the Mexican flounder (*Cyclopsetta chittendeni*; Centeno-Chalé et al. 2015). Vidal-Martínez et al. (2015) related the probability of occurrence of *Oncomegas wageneri* (Cestoda: Trypanorhynca) among other factors to the concentration of hydrocarbons. In the coastal lagoons of the northern Yucatan Peninsula, Pech et al. (2009) used the checkered puffer (*Spheroides testudineus*) and its parasites as environmental indicators. Gold-Bouchot et al. (2017) used transcript abundance and pollutant analyses of two fish species to assess environmental impacts in the Veracruz Reef System.

Histopathology has also been used as a tool to evaluate the effects of pollutants. Gold-Bouchot and coworkers (1995, 1996) used the histopathology of the eastern oyster (*Crassostrea virginica*), to assess the impact of the oil industry in three coastal lagoons in the southern Gulf. Strong dose-response curves were reported for cadmium and the Unresolved Complex Mixture (UCM) of hydrocarbons in the oyster soft tissue.

Biomarkers at different levels of biological organization have also been used as tools for the evaluation of pollution effects. Zapata-Pérez et al. (2005) used ethoxycoumarin O-deethylase (ECOD, an enzyme closely related to EROD, in the Cytochrome P-450 group) activity and vitellogenin induction in pink (*F. duorarum*) and white shrimp (*Litopenaeus setiferus*) to evaluate the status of shrimp populations exposed to pollutants. Relationships between enzyme activity and gene expression and hydrocarbons were found. Gold-Bouchot et al. (2007) used biomarkers in the eastern oyster in Laguna de Términos, a protected area in the southern Gulf in the delta of the Grijalva-Usumacinta River. The catfish (*Ariopsis felis*) was used to evaluate the effects of pollutants in coastal lagoons from the Yucatan Peninsula (including Laguna de Términos) by Zapata-Pérez et al. (2007). Endocrine-disruption was evaluated by determining transcript abundance of the vitellogenin gene, and a relationship to total DDT and PCB concentrations in the liver was found.

Currently there are two ongoing projects in the southern Gulf with relevance to the fate and effects of marine pollutants. One is the GOMRI-funded "The Center for the Integrated Modeling and Analysis of the Gulf Ecosystem" (C-IMAGE-II), hosted by the University of South Florida, a collaboration between US and Mexican researchers including research cruises through the entire Gulf. The second is: "Implementación de redes de observaciones oceanográficas (físicas, geoquímicas, ecológicas) para la generación de escenarios ante posibles contingencias relacionadas a la exploración y producción de hidrocarburos en aguas profundas del golfo de México [Implementation of oceanographic observation networks (physical, geochemical, ecological) for generating scenarios in the face of possible contingencies related to the exploration and production of hydrocarbons in deep waters of the Gulf of Mexico]," a project funded by CONACYT and lead by CIGOM. This project involves over 100 Mexican scientists and international collaborations with institutions in the United States and Europe.

One interesting effort being carried out in Mexico is the validation of environmental quality indices for tropical marine ecosystems, such as the TRIX, a trophic index for marine waters developed in Europe by Vollenweider et al. (1998). This index uses values for inorganic nutrients (total nitrogen and phosphorous), chlorophyll *a*, and oxygen saturation. For benthic communities, the BENTIX Index (Simboura and Zenetos 2002) is also being adapted to the species found in the southern Gulf. The adapted index has been named Benthic Index for the Campeche Sound (BICS) (Daniel Pech, ECOSUR, personal communication). It would be expected that both adapted indices would be useful also in the northern Gulf, as the fish species that have been used in studies in the southern Gulf are also present in the northern Gulf. The presentation included in this report contains some examples of the kind of studies being done now in the southern Gulf.

1.2.5.3 Future Directions

Some knowledge gaps in the literature search done for this chapter were found, particularly for the southern GOM. One interesting finding is that there are some differences in the approaches being used in the northern and southern Gulf to assess the impact of the oil industry. More collaboration between researchers in Mexico and the United States would be desirable to exchange experiences, and particularly design joint projects. Some gaps detected for the southern Gulf are as follows:

- There are no published data on the use of epigenetics and metagenomics in fish or other marine organisms to assess the impact of hydrocarbons or other pollutants associated with the oil and gas industry.
- Adaptation of the TRIX and BENTIX indices must be completed and published, so their use in the northern Gulf can be evaluated and used.
- There is a lack of baseline studies related to the influence of the variability of environmental driving forces on environmental impact assessment.

- Finally, there are no Gulf-wide efforts that allow the study of the GOM as an LME, with the only exception being the C-IMAGE-II consortium and CIGOM, which is primarily focused on the southern Gulf. Thus, meso- and macroscale studies are needed.

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1.2.6 The State of International Science in the Gulf of Mexico: Cuban National Perspectives

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1.2.6.1 Abstract

Cuba, a long and narrow island, is almost entirely a coastal zone and conflicts for the use of the space are inevitable. This overview briefly describes the three primary marine ecosystems in Cuba, mangroves, seagrasses, and coral reefs, and effects of some of the important natural and anthropogenic stressors such as hurricanes, pollution, and overfishing. To avoid user conflicts and organize activities, a variety of regulations have been promulgated with decision making guided by the advice of scientific researchers. Research and educational programs are closely related to the main problems that face marine environments and coastal zones in Cuba, but also to the greater Caribbean region including the GOM.

1.2.6.2 Introduction

As a part of the Caribbean Sea, Cuba is the largest archipelago (ca. 110,000 km^2) in the region (Wilkinson 2008). One of its most prominent characteristics is that it is long (1,250 km) and narrow (191 km across its widest point and 31 km across its narrowest point), and thus, almost the entirety of Cuba can be considered as a large coastal zone. These characteristics imply that many different users, activities and conflicts coexist in the same space. To avoid conflicts and organize activities, the state has enacted a variety of different legislation and regulations with the decision-making process guided by the advice of scientific researchers. The majority of research centers that are focused on studies related to the marine environment are in the city of Havana, Cuba's capital. Research and educational programs are closely related to the main problems that face marine environments and coastal zones in Cuba, but also to the greater Caribbean region including the GOM. Because of this, the goal of this contribution is to offer a general overview about the main Cuban marine ecosystems, the natural and anthropogenic stress that they receive, and the main lines of research that different Cuban marine institutions deliver through national and international collaboration. Briefly, I'll mention the role of women as heads of marine or environmental institutions, and in particular, "Ocean Mother of Cuba," Dr. María Elena Ibarra Martín, who was the director of the Center for Marine Research at the University of Havana (CIM-UH) for almost 25 years.

1.2.6.3 Physical and Climatological Setting

Because of its long and narrow form, the island of Cuba is very dependent on the climatic conditions of the area. The island has a tropical climate, with an average annual precipitation of 137.5 cm, and a daily tidal range of around 20 cm. The main two seasons that produce climatic differences are: 1) the dry season from November to April, and 2) the rainy season from May to October (INSMET 2017). During the rainy season, we receive around 80% of the total annual rainfall related to the passage of cold fronts and hurricanes. Changes in the patterns of rainfall leave the island very susceptible to drought. For example, during a recent three-month period (May–July 2017), there was a severe dry period in the central and eastern Cuban provinces, and this has been very damaging to agriculture, soil health, and human populations. In fact, during the first six months of 2017, the government implemented several special actions to conserve water and increase public awareness about the extreme dryness in some areas of the country. Some provinces (Villa Clara, Sancti Spíritus, Santiago de Cuba, and Guantánamo) have suffered more than others (Figure 10) and have been the focus of the special actions mentioned above. Of course, this situation has also caused many rivers to go dry, and therefore, freshwater discharge into the coastal zone has been reduced. The consequences of this situation on coastal marine ecosystems have been severe—mangroves have started to become affected, many estuaries have dried up, and many fish and other marine organisms have died. At the same time, the natural flow of nutrients to seagrasses and coral reefs from river discharge has been interrupted.

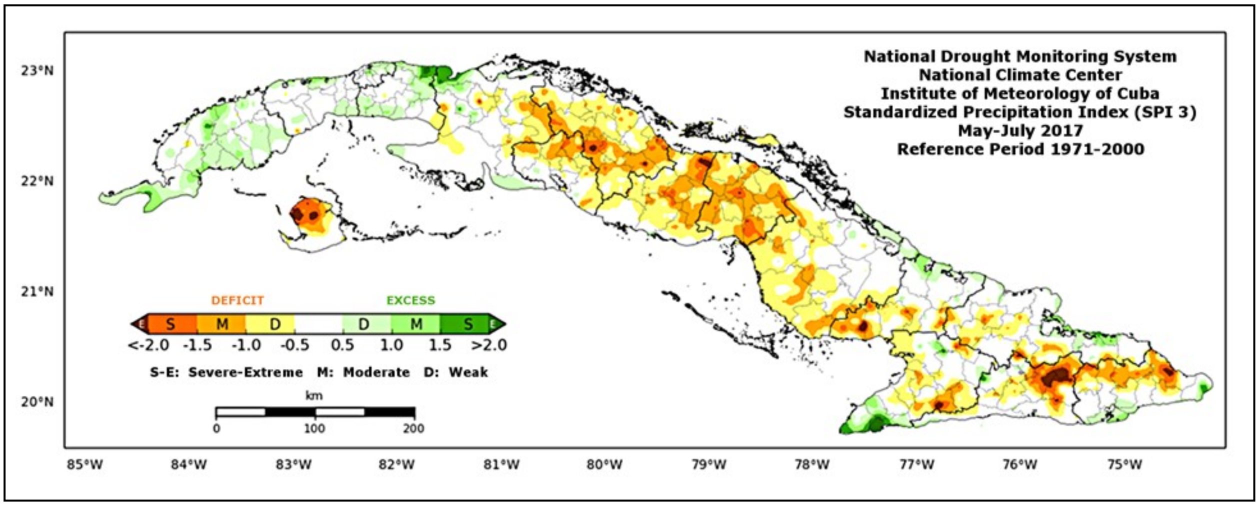

Figure 10. Cumulative rainfall during May–July 2017, expressed as Standard Precipitation Index values.

Modified from INSMET (2017).

Another important component of the Cuban climate system is extreme meteorological events. Hurricane season runs from June 1 to November 30. However, between 2010 and 2016, no significant hurricane passed through the western Cuban provinces and only one big hurricane (Sandy) affected the eastern Cuban provinces (Figure 11). This period of reduced hurricane activity has also had a negative impact on marine communities by contributing to increased temperatures in coastal waters.

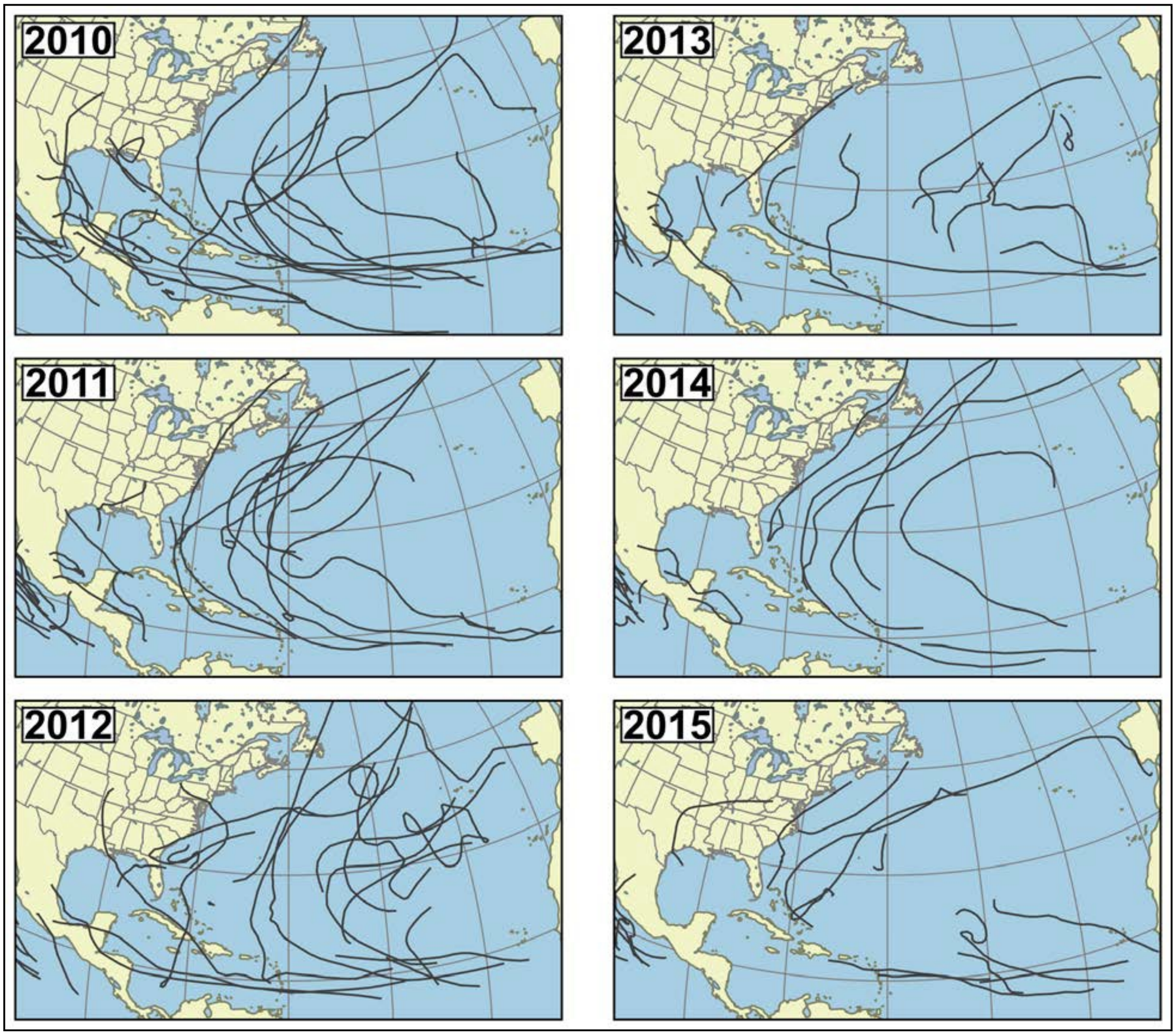

Figure 11. Route of extreme meteorological events for different storm categories during 2010–2015.

Source: Basemap shapefiles courtesy of Natural Earth. Historical hurricane tracks courtesy of NOAA National Hurricane Center. Figure prepared by M. Besonen.

One of the most important oceanographic factors is related to the currents present in the Caribbean Sea and adjacent regions (Figure 12). In general, system currents that involve Cuba and pass through the Caribbean and GOM are associated with strong physical, genetic, and ecological connectivity (González 2000). This characteristic is the basis for much scientific research, from oceanography to ecology, to understand the function and structure of our marine ecosystems, and the migration patterns of our target, protected, and charismatic marine species. Local currents also play a role, for example, with self- recruitment. In some cases, these local currents create upwelling and increase nutrient concentrations in our typically oligotrophic waters.

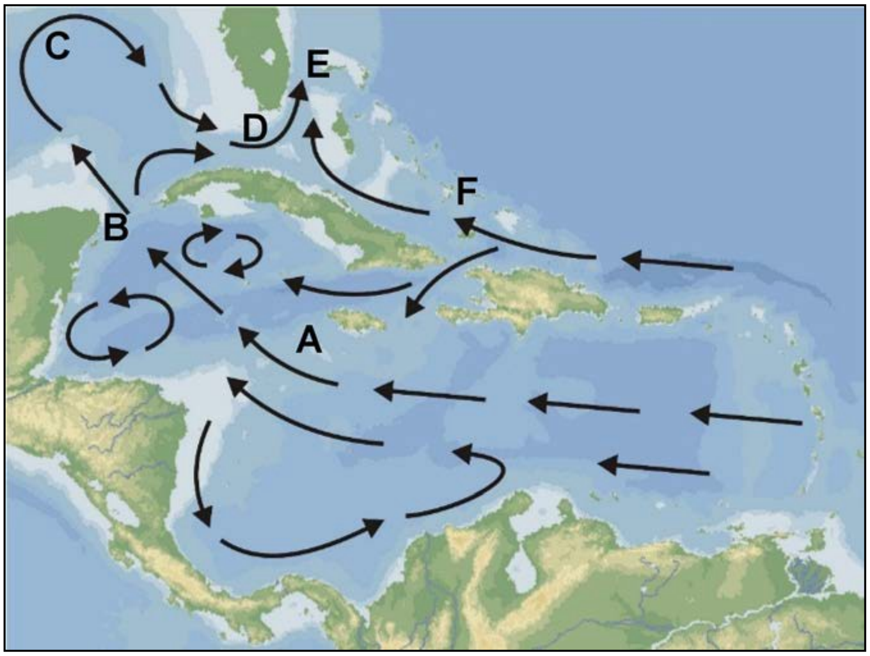

Figure 12. Surface currents in the Caribbean Sea and adjacent waters.

The main currents are: A-Caribbean, B-Yucatan, C-Loop Current, D-Florida; E-Gulf Stream, and F-Antilles. From González (2000).

1.2.6.4 Dominant Marine Ecosystems

It is difficult to discuss Cuba's main marine ecosystems separately from one another (González-Díaz et al. 2015). As mentioned before, from an oceanographic to ecological perspective, strong horizontal connectivity exists throughout the complex (from land to sea) involving mangroves and estuaries, seagrasses, and coral reefs (Figure 13).

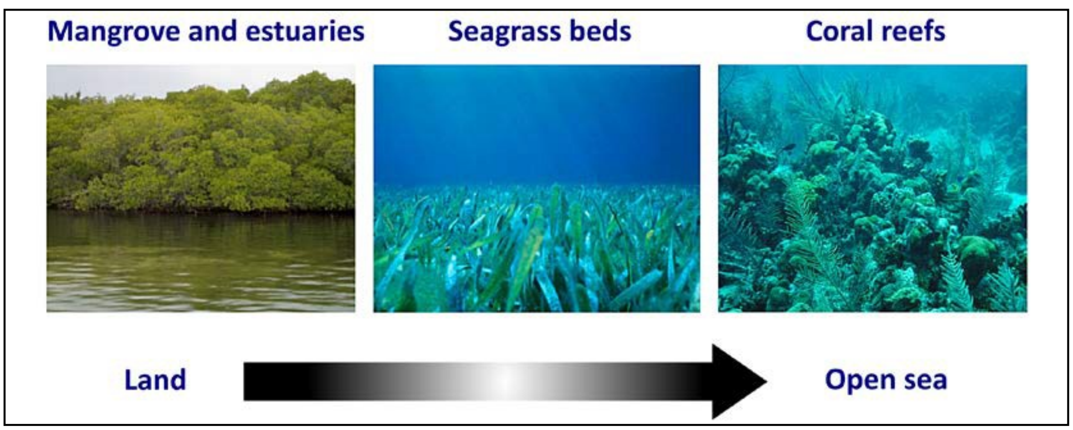

Figure 13. Typical zonation of the complex of primary Cuban marine ecosystems.

From land to sea this includes mangroves and estuaries, seagrasses, and coral reefs.

In the case of mangroves, they occupy 5.1% of the Cuban archipelago surface, which represents approximately 26% of the forest cover in the country. This implies that mangroves occupy between approximately 60–70% of our coastline. The four species of mangroves that we have are: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and button mangrove or buttonwood (*Conocarpus erectus*). This ecosystem has a high ecological significance in our research given that it represents the transition between land and sea (Menéndez and Guzmán 2006) as well as nursery area for juveniles of many commercial, target, and endangered species of the Cuban platform. This last ecological function, in addition to the role of mangroves as natural protection for the coastline and a natural filter for sediments and contaminants, increases the economic value of this ecosystem and justifies the protection measures that have been established.

Seagrasses dominate the ecosystem that can be found just adjacent to the mangroves (Martínez-Daranas 2006). Vertical distribution of seagrasses starts in the intertidal zone and reaches to approximately 6–7 m depth. This ecosystem is highly influenced by environmental factors, especially by light penetration and water transparency. Following Suárez et al. (2015), six species of marine phanerogams can be found in Cuba: turtle grass (*Thalassia testudinum* Banks ex König, 1805) which is the most abundant species in Cuban waters; manatee grass (*Syringodium filiforme* Kützing in Hohenacker, 1852); shoalgrass (*Halodule wrightii* Ascherson, 1868); widgeongrass (*Ruppia maritima* Linnaeus, 1753); and the clover grasses (*Halophila decipiens* Ostenfeld, 1902) and (*H. engelmanni* Ascherson, 1875). Shoot density varies greatly (20–4000 shoots/m^2) as does biomass (0.05–2 kg/m^2). Seagrasses play an important role in stabilizing sediments in addition to providing reproduction and feeding area for many species of ecologic and economic significance.

In the case of coral reefs, Cuba has ~3,966 km of coral reef tracts along 98% of the long shelf edge (Wilkinson 2008). Cuban coral reefs can be found along almost the entire border of the Cuban shelf and many of the gulfs. More than 50% of these reefs are separated from the mainland by keys and/or broad shallow lagoons that contain many patch reefs. The main coral reef systems in the south of Cuba, namely “Los Canarreos” and “Jardines de la Reina” (Gardens of the Queen) are considered among the least damaged reefs of the Caribbean Sea (Wilkinson and Souter 2008). Ecologists are interested in coral reefs for many reasons: 1) reefs exhibit the highest biodiversity of species among marine ecosystems, 2) many species of economic significance live in coral reefs as adults (e.g., grouper, snapper, spiny lobster), and,
3) reefs protect coastal zones because the hard skeleton of the corals and three-dimensional structure of the reef is physically strong (González-Díaz et al. 2015).

1.2.6.5 Main Threats to Cuba´s Marine Ecosystems

Cuban marine ecosystems suffer from the same common natural and anthropogenic impacts that affect all ecosystems in the Caribbean and GOM. Because of this, the essence of those processes and impacts will not be described here. Instead, this section focuses on the general situation in Cuba regarding these impacts.

In terms of anthropogenic impacts, one of our major concerns is related to subsistence overfishing, particularly on the reef directly offshore from the city of Havana (González-Díaz et al. 2015). Fishing this reef is illegal, so it is difficult to quantify or obtain precise statistics about how many fishermen work this reef, with what frequency they fish, and exactly which route they use. This kind of fishery usually uses spear guns and takes any kind of commercial fishes and invertebrates (e.g., octopus), no matter the size and legal protection level of the species. Usually, these fishermen do not use boats because Havana’s coastal margin reefs are easily accessible from shore. Other fishermen set nets perpendicular to the coast, which is also illegal (Figure 14). All of these activities result in overfishing of our marine resources and cause substantial damage, not just to the species that are fished, but the entire ecosystem, as well.

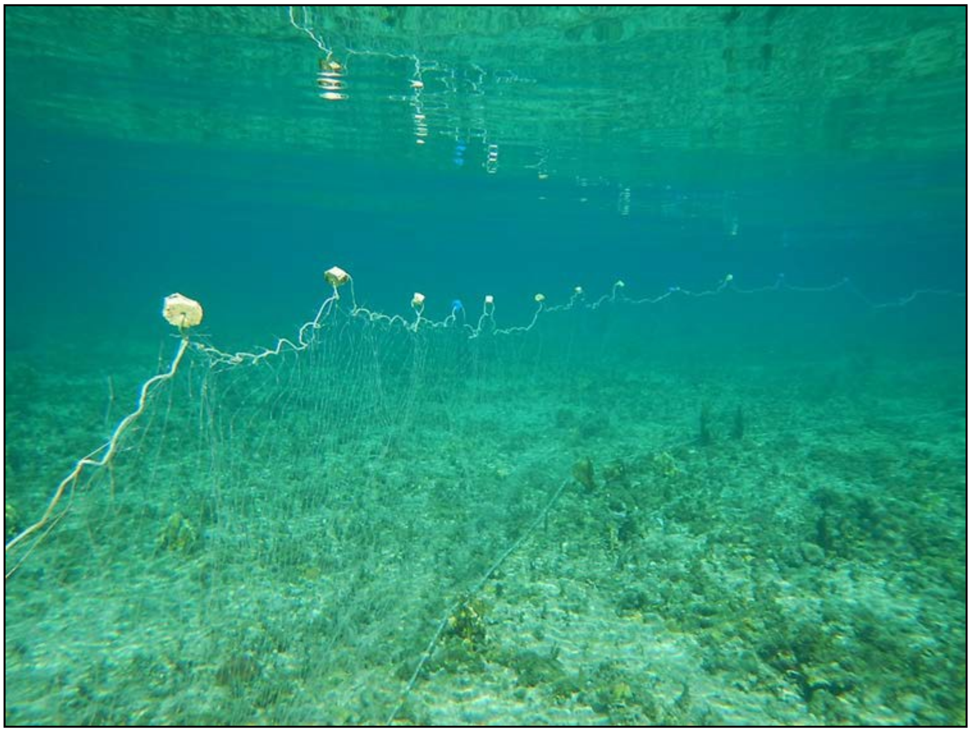

Figure 14. Net established at 1.50 m, perpendicular to coast line of Baracoa Beach by illegal fishermen.

The photo was taken on 28 June 2017 by P. González-Díaz.

Cuba has a strong legal framework and different kinds of regulation to avoid this fisheries situation. Among others, relatively recently the Office of Fisheries Regulations within the Ministry of Food Industry (MINAL), established a new regulation prohibiting the catch of parrotfish. In general, we have laws related to the management of fisheries, the coastal zone, and MPAs (Ripoll et al. 2015). These regulations and laws are continuously reviewed and improved. However, good enforcement is always difficult to establish and maintain. This is generally because the stressed economic situation makes it a true challenge to develop and support a proper enforcement infrastructure (e.g., appropriate number of inspectors, boats for patrolling the areas, and ongoing maintenance and fuel expenses for the boats).

Unfortunately, the situation described above is also very common in the other countries of our region, even in the countries with better economic situations. Fortunately, Cuba does not suffer from some fishing methods that are relatively common in the Caribbean region, for example, dynamiting in the reefs. For the legal framework, we also focus on increasing knowledge and capacity building in the areas related to fisheries. Different kinds of courses and workshops are delivered by different institutions, for example, the Center for Fisheries Research (CIP-MINAL) and CIM-UH. These courses focus on stakeholders, fishing communities, the general public, children and young people, and even researchers.

Another one of our important concerns is related to the impact caused by sedimentation and land-based pollution. This impact is directly related to the fact that the main Cuban cities were constructed along the coast in the sixteenth century. Seven coastal cities were originally founded at that time, but just two big cities with high human population densities exist today: Havana (total population: 2,117,343; density: 2907.4 inhabitants/km^2) and Santiago de Cuba (total population: 1,053,914; density: 169.2 inhabitants/km^2) (Anuario Estadístico de Cuba 2014). Both cities have a main bay where important economic and industrial activities have been developed. In the case of Havana Bay, its being one of the most polluted in the region, motivated the Cuban government to establish a special recovery plan for the bay (Álvarez 2016). The plan includes moving all industrial facilities to Mariel Bay where environmentally-friendly facilities using new technologies will be constructed. At the same time, the margin of Havana Bay will become a tourist route that includes museums, art houses, visitor centers, and other similar attractions (Álvarez 2016). Other local sources of land-based pollution are related to the margins of rivers and the coastal zone in front of cities. In these cases, strong work by the government and different environmental agencies is needed to avoid pollution problems. In general, they work under the umbrella of the laws and decrees related to integrated coastal zone management and land-use planning in each province and municipality (Ripoll et al. 2015).

Direct physical damage is one of the minor types of damage that face our marine ecosystems. The magnitude of the impacts from direct damage is much less than either overfishing or pollution. In some places, boats have caused anchor damage to reefs. However, tourist places have very strict rules, and even more if they are in any type of MPA. In the case of the Gardens of the Queen coral reef system, for example, park authorities are in the process of buying and establishing the proper buoys for different kinds of tourist vessels. In the meantime, tourist boats are not allowed to enter the area except for the boats of the tourist business that manages the area in collaboration with the park authorities. All of these rules are in the management plans for protected areas. A similar situation takes place in Maria la Gorda, where the dive shop and tourist enterprise are constantly advised by researchers from Guanahacabibes National Park.

The effects of climate change that we face are the same that affect all islands in the Caribbean region and GOM. In general, sea-level rise, coastal erosion, and acidification of the ocean are three major concerns for most people, from different levels of the government down to human communities that live in the coastal zone. These themes serve as the focus for many research projects from different perspectives that are delivered by Cuban scientific institutions. We study from the very basic ecology and biology of species to management and conservation strategies. At the same time, the Cuban government has implemented different kinds of studies related to prevention and vulnerability risks. And for quite some time, different actions have been undertaken to solve or at least mitigate the effects of sea-level rise on coastal communities. One action, for example, is that villages are constructed farther from the coast for communities in very vulnerable coastal areas. Thanks to modeling studies of sea-level rise under different future scenarios, all territorial management plans include analyses of these aspects, and the development of each municipality and province is carefully planned. Now, there is clear recognition that construction and building on the dunes must be avoided, and similarly, changing the natural dynamics of coastal areas must also be avoided. Furthermore, the extraction of sand from beaches for construction or other purposes is completely prohibited (Ripoll et al. 2015).

Few studies about the coral communities in Cuba exist before 1998 (Alcolado et al. 2000; Guardia 2000). But following the first big coral bleaching event that year in the Caribbean, Cuban scientists started to track the health status of our corals and benthic community in general. Many research efforts at the Institute of Oceanology and CIM-UH occured during these years. Later, other institutions, such as the National Aquarium of Cuba, Guanahacabibes National Park, and the Center for Coastal Ecosystems Research, among others, began working on these same themes. Now in Cuba, we have good general information about the health status of corals. It is not yet enough, but at least it provides a general overview of the situation at the moment, and we have identified the main knowledge gaps related to coral bleaching and diseases. With regard to bleaching, in general, we have some very broad remarks:

1. The sensitivity of corals to bleaching is not the same for all Cuban reefs (González-Díaz 2010). The specific situation with respect to the natural and anthropogenic stress on any individual reef is crucially important to the health status of its corals. Corals in a relatively

"pristine" reef are more vulnerable to bleaching. We explain this based on water transparency and high irradiance in places with significant land-based pollution and eutrophication processes (e.g., the margins of Havana Bay and the Almendares River). Both impacts produce a dark layer that reduces water transparency, and thus, helps to protect against strong irradiance. We observe the prevalence of bioerosive organisms affecting the corals at these locations.

2. The sensitivities of species are unequal. In Cuban reefs, *Siderastrea siderea* is the first coral species that starts to bleach, but at the same time, it is the most resistant to bleaching and usually recovers (González-Díaz 2010).
3. There is little evidence of diseases observed in Cuban reefs. Probably, the most common one is black band and dark spots. Black band mainly affects species of massive genera such as *Pseudodiploria* and *Orbicella*. Dark spots are frequently found in *S. siderea* (González 2004).
4. The passage of hurricanes seems to bring positive results to corals if you compare bleaching results in years with and without hurricanes. The comparison between 2008 (three hurricanes) and 2009 (no hurricanes), shows clear differences for *S. siderea* regarding the percent of colonies bleached (Figure 15) in different coral reef sites offshore of Havana Province. Since 2010, no strong hurricanes have affected the western Cuban provinces and water temperatures have remained high (Figure 16), resulting in increased sensitivity of corals to bleaching. During very important bleaching events in the Caribbean in 2005 and 2008, the western Cuban provinces were impacted by several severe hurricanes in each year (2005: Katrina, Rita, and Wilma: 2008: Gustav, Ike, and Paloma). These caused the water temperature to decrease and corals recovered very quickly and did not sustain major damage. Since 2010, no hurricanes have passed the western side of the country and the situation for corals has started to change for the worse (Figure 17).

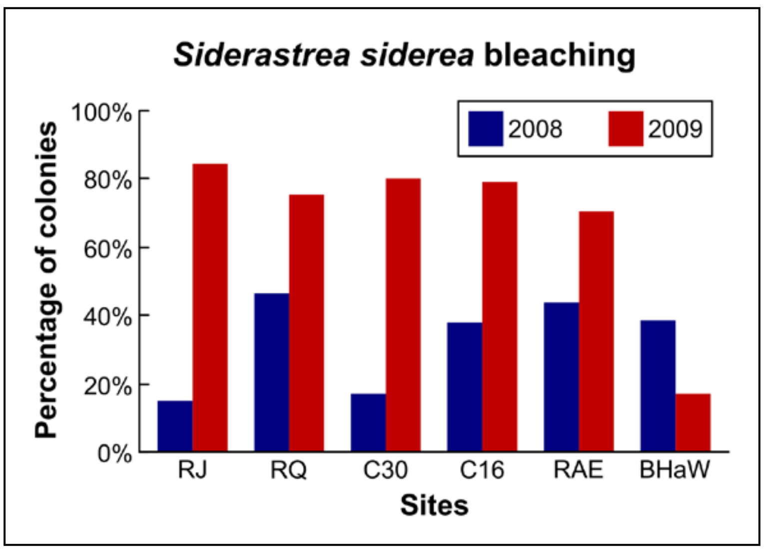

Figure 15. Percentage of bleached colonies of *S. siderea* during a year without a hurricane (2009) and with four severe hurricanes (2008).

The sites include: RJ-Jaimanitas River, RQ-Quibú River, C30-Calle 30, C16-Calle 16, RAE-east of Almendares River, and BHaW-west of Havana Bay.

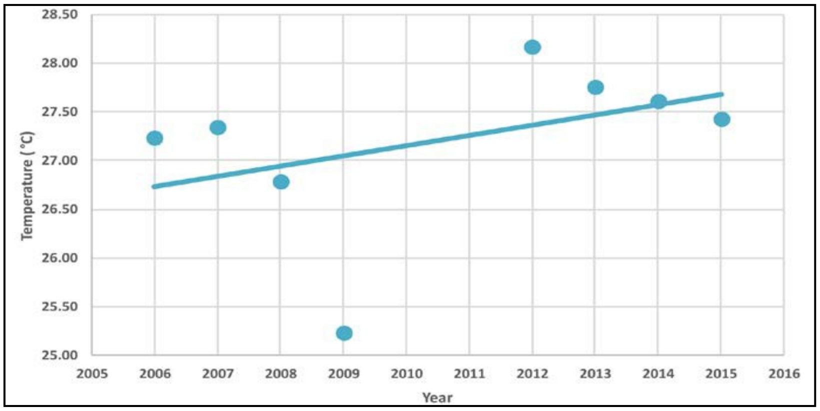

Figure 16. Trend of increasing temperature based on measurements (every 30 minutes) from a Hobo data logger on a reef in front of Havana city (2006–2016).

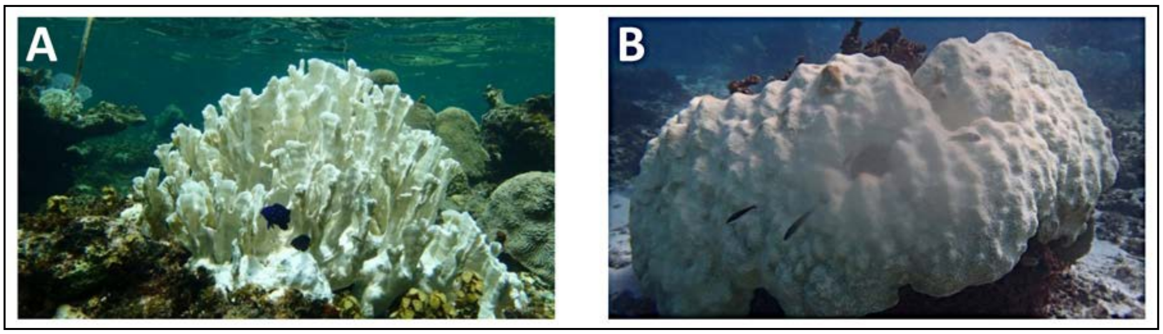

Figure 17. Possible cumulative effects of increased temperature due to the absence of hurricanes caused strong bleaching of Cuban reefs in 2015.

The photos show (A) *Millepora complanata* in Punta Frances, Isle of Youth, and (B) *Orbicella faveolata* in Cayo Largo del Sur. Both photos were taken in November 2015 by P. González-Díaz.

1.2.6.6 What Can Cuba Do to Get Out in Front of This Scenario?

To avoid or diminish the natural and anthropogenic impacts on coastal marine ecosystems, and taking into account the economic constraints faced by Cuba, we have three main strategies:

1. Combine research with capacity building.

   These actions involve not only undergraduate and graduate programs in the universities, but any kind of research actions or projects that are delivered by any institution such as trainings, workshops, or courses (Figure 18). Thanks to such efforts, for example, in Guanahacabibes National Park, almost all the park guides have Master of Science degrees and speak two or three languages. Also, many park guides can conduct monitoring studies in the area and help with data analyses. Regarding undergraduate and postgraduate programs, the majority are delivered by CIM-UH. The most famous are the MS and PhD programs in Marine Biology and Aquaculture.

   Also, the universities of Havana, Cienfuegos, and Oriente deliver a joint Master's program in "Integrated Coastal Zone Management." A special characteristic of this last program is that it encourages students to provide recommendations, through research, on how to solve any coastal zone conflict. This is possible because the program has been designed to focus on themes that range from larger scale general issues to smaller scale problems that are specific to particular provinces or municipalities. This allows students, through their thesis research, to analyze problems that affect their local area of interest, propose appropriate solutions, and thus, contribute to local development.

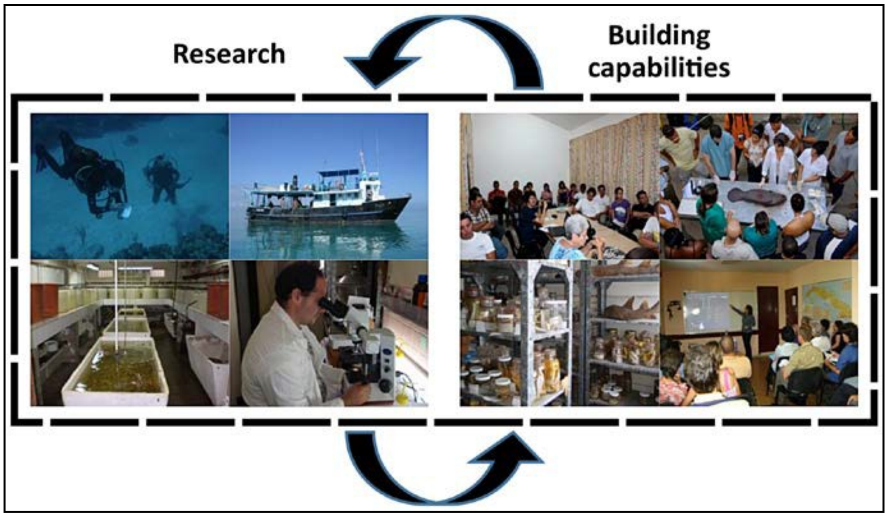

Figure 18. One of the main strategies to avoid or solve impacts on coastal marine ecosystems is to combine research with capacity building for Cuban scientists.

2. Establish research themes and priorities.

   Even when each institution has its own mission and vision, general research lines distinguish our efforts. Every three to five years, scientific councils at each institution analyze the research lines and priorities. Basically, these research lines are based on scientific questions, on a gap in knowledge, or on a specific problem that it is necessary to solve. Usually, the final component of the research is to provide our recommendations to different agencies in our government. The main users of scientific results are the Ministry of Tourism (MINTUR); the Ministry of Science, Technology and Environment (CITMA); MINAL; the Ministry of Public Health (MINSAP); and different levels of the government (e.g., local, municipal and provincial), among others. This is a very general list showing the main research lines that are being pursued at different Cuban marine institutions:

   a. Oceanographic, ecologic and genetic connectivity
   b. Population genetics
   c. Coastal processes
   d. Marine meteorology
   e. Biodiversity patterns
   f. Paleoclimatic reconstructions
   g. Effectiveness of MPAs
   h. Endangered species (sharks, manatees, turtles)
   i. Invasive species (lion fish, clarias)
   j. Bioproducts
   k. Fisheries management and research in stock fisheries
   l. Effects of natural and anthropogenic impacts
   m. Health of coastal marine ecosystems (mangrove, seagrass beds and coral reefs)

n. Global change
o. Resilience processes in coastal marine ecosystems
p. Conservation and management of coastal ecosystems

3. National and international collaboration.

We deliver the research lines mentioned above, in part, thanks to strong national and international collaboration. These two kinds of collaboration have different characteristics and benefits. In general, both are based on established projects and continuous academic exchange. One very useful tool for collaboration is networks. At the university level, we have two very prestigious networks: the Local Development network and the Environmental network. At the international level, networks such as Integrated Coastal Zone Management, Ibermar, among others, are also very active.

At the national level, we have different Ministries (Ministry of Higher Education [MES], CITMA, and MINAL) that oversee universities, agencies, aquariums, research centers, academic institutions, and similar, all of which usually work very closely with one another (Figure 19). This close integration has the advantage of permitting the integration of knowledge and complementing scientific results while saving resources. Some of these institutions directly deliver research projects while others such as the National Center for Protected Areas (CNAP) are responsible for conservation strategies and implementing management.

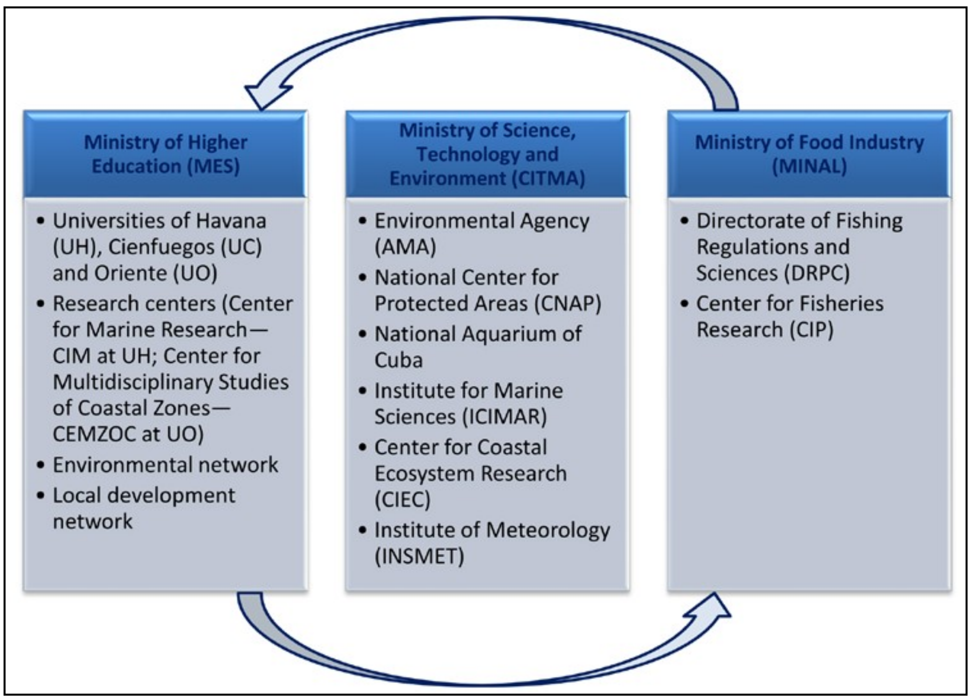

Figure 19. Cuban institutions from different ministries that work closely together on marine research and conservation.

At the same time, international collaboration helps provide financial support for research, integrates our scientists into international knowledge and research networks, and increases knowledge in many different research areas through common projects or academic graduate programs. It also allows us to publish our results in prestigious scientific journals and to attend international conferences. In particular, the roles of several different institutions and universities (e.g., HRI at TAMUCC, the Gund Institute at University of Vermont, and Florida Atlantic University) have been crucial. Non-governmental organizations have also been very important in supporting our research, and some have had ongoing work in Cuba in collaboration with various national institutions for more than ten years (e.g., The Ocean Foundation, Environmental Defense Fund).

1.2.6.7 One Last Noteworthy Aspect: Cuba´s "Women of the Sea"

One noteworthy aspect of our science in Cuba is the large number of women that not only work as researchers and faculty, but also have high positions as heads of institutions or even as ministers in the government. In Cuba, there exists much sociological research related to gender and the different views and perspectives that men and women have about the best way to solve problems. Some of this research concludes that women are more organized and better at managing conflicts and creating development strategies. Whether the conclusions of this research are true or not, the reality is that the heads of two ministries, CITMA and MINAL, are women. The same is true for three vice ministers of MES. Among different centers or institutions, the Environmental Agency (AMA), the National Aquarium of Cuba (regulated by CITMA), and CIM-UH, are led by women; the president of the University of Oriente is also a woman, and in the University of Havana, four vice presidents are women, too. In Cuba, women have exactly the same rights as men, and this includes access to the same work positions with the same salary.

The success of women as heads of institutions has resulted in some of them staying in their positions for long periods. For example, Dr. María Elena Ibarra Martín (Figure 20) was the Director of CIM-UH for almost 25 years. She is very well known not only among marine scientists, but also among the greater Cuban environmental scientific community. She is much respected for her encouragement and brilliant efforts in opening new avenues and directions for the development of Cuban marine research. One of the most successful projects that she led was the conservation and protection of marine turtles on the Guanahacabibes Peninsula. The results of this project resulted in better knowledge about migration patterns of turtles, reproduction, nesting and genetic characteristics, and the impact of hurricanes changing beach profiles and the consequences for turtle's nests. This research effort lasted for more than 15 years, and she was involved in all of the research projects. Because of this, when she passed away in May 2009, her ashes were spread over a beach on the Guanahacabibes Peninsula. This marine turtle project is just one good example of the many projects that she conducted herself or strongly supported.

Figure 20. Dr. María Elena Ibarra Martín was the Director of CIM-UH for almost 25 years.

All of Cuba's environmental and marine scientific communities are very grateful to her and remember her with great fondness. Photograph © David E. Guggenheim (2003) and used with permission.

Another aspect of her work is related to her very special role in establishing successful bridges for international collaboration projects in marine science and academic exchange, mainly with US institutions. She was the first marine scientist that opened the doors and made space for academic exchange with American colleagues. She understood very well that marine species do not understand political boundaries, and instead, they migrate through regions, countries, seas, and oceans, which keeps us close. She had the idea that if we really want to understand the environment around us, work seriously to manage our GOM and Caribbean Sea from a sustainable perspective, and avoid the effects of climate change, we must work together as an alliance. Cuba, Mexico, and the United States are environmentally close because of the marine environment that we share and the common problems that we face, but also because of the good science that we produce together and our fruitful and productive academic exchanges. Many different institutions in the three countries are part of this alliance, but without doubt, the role of HRI in this effort has been crucial and impressively productive. Dr. Ibarra recognized this in different scenarios and we appreciate her understanding of this need for collaboration as another important lesson about scientific sisterhood and human values.

1.2.6.8 Acknowledgements

I would like to express my gratitude to HRI for inviting the Cuban delegation to the State of the Gulf of Mexico Summit and the Gulf of Mexico Workshop on International Research meetings in March 2017. I am especially grateful to Dr. Larry McKinney for his constant efforts and support in working towards solving the common problems that face the three Gulf countries (Cuba–Mexico–United States). Also, I really appreciate Dr. Mark Besonen's assistance with polishing the grammar and figures for this manuscript.

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1.2.7 The Socioeconomic Environment of the Gulf of Mexico

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1.2.7.1 Abstract

Within the Gulf of Mexico, region socioeconomic science has been characterized by fits and starts. This trajectory has limited the understanding of how Gulf societies are responding to social, economic, and environmental change. BOEM has addressed some of these gaps through targeted research efforts. Still, significant opportunities exist for developing a socioeconomic research program that can enhance biophysical efforts and demonstrate the societal impact of current work.

1.2.7.2 Introduction

Socioeconomic science within the GOM region has been characterized by fits and starts leaving many gaps to fill and opportunities for researchers. Take for example the 1992 National Research Council report on social and economic studies undertaken by the Minerals Management Service (MMS). While the Gulf accounted for the majority of the MMS's oil and gas revenue, "the panel found no documentation of a systematic program for identifying and analyzing important socioeconomic issues for study in the Gulf of Mexico Region" (NRC 1992). Only 11 studies had been conducted in a 15-year period at the time of the panel's report. The MMS—now BOEM—changed course and, in the 16 years since the report, has conducted 87 studies in the Gulf (BOEM 2017).

The effort and funding around socioeconomic science in the Gulf still falls far behind the bio-geo-physical sciences. A number of organizations and individuals have called for specific actions. The 2013 "Gulf of Mexico Research Plan" (MASG 2013) highlights two particular needs:

- Examine the public's perception of sea-level change by evaluating hazard-related communications and changes in behavior in relation to hazard mitigation and identify approaches that local governments are employing to adapt to sea-level change.
- Determine how storm surge, subsidence, and sea-level change affects ecosystems, native coastal habitat, wetland composition, saltwater intrusion, coastal flooding, cultures, agriculture, and human health.

The National Academies of Science, Engineering, and Medicine's Gulf Research Program has set goals that specifically address human and community needs (NRC 2014):

- Improve understanding of the connections between human health and the environment to support the development of healthy and resilient Gulf communities; and,
- 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.

Similar needs are identified for Mexico. Ramos et al. (2015) noted the lack of communication between municipalities and higher institutions (e.g., researchers, community organizations) that needs to be addressed and that many of the indicators for climate change monitoring are vague, hard to measure, and don't connect with people in the community. Soares and Sandoval-Ayala (2016) suggest that:

- More research is needed on long-term impact of climate change on low resilience and marginalized communities.

- There is a need to examine how communities think about climate change, keeping in mind that it is not always the immediate (hurricane) changes but the gradual change that is important.
- There needs to be the development of techniques to reach “into” the communities and have more informed decision making at the local level (not just high-level stakeholders).

1.2.7.3 Socioeconomics Characteristics of “One Gulf”

This section relies exclusively on some of the analyses described in “Gulf 360: State of the Gulf of Mexico” (Yoskowitz et al. 2013), unless otherwise noted, to effectively convey the socioeconomic connections between the three countries in the Gulf region and between people and coastal and marine resources.

Geopolitical divisions and governmental structures deal only with portions of the landscape, fractions of a watershed, and with pieces of a habitat, but muc,h of our economic activity and ecology goes beyond borders. This section will focus only on a few of the important human dimensions of our coasts: political boundaries and population, fisheries extraction, transportation, and protected areas.

There are three key elements that define this geographic “space” called the GOM: the land-ocean interaction, the human activities that occur, the shape of the landscape/seascape, and the natural resources that feed the needs of the population. As was aptly said in *Gulf at a Glance: A Second Glance* (NOS 2011) about the US portion of the Gulf, which is relevant for the entire region:

> The well-being of the Gulf of Mexico region depends on a suite of benefits that flow from healthy coasts: food, clean water, jobs, recreation, and protection from hurricanes. But the ability of the Gulf coast to deliver these benefits is being eroded by the extensive environmental alterations we have made to the region’s coastal ecosystems. In some cases, these benefits are further eroded by changes in climate. Whatever the cause, these changes threaten to compromise the health and economic well-being of our coastal communities . . .

1.2.7.3.1 Political Boundaries and Population

The administrative divisions of Mexico and the United States are states, while in Cuba its administrative divisions are designated as provinces. In the United States, the states are further divided into counties, or in the case of Louisiana, parishes. In Mexico, the states are divided into *municipios* or municipalities, which are equivalent to counties.

The number of municipalities in the Mexican GOM coastal region is extremely dense compared to the United States and Cuba. For example, along the GOM coastline, Mexico has four times more municipalities than the United States has counties and parishes even though the land area in Mexico is only about 20% larger (442,000 km^2 for Mexico and 370,000 km^2 for the United States).

Pockets of intense density and areas that are sparsely populated characterize GOM coastal population distribution, and there are more than 50 million people living along the coastal margins within the region (Figure 21). In Mexico, states such as Veracruz report population densities of 106 per square kilometer, whereas densities in Tamaulipas and Quintana Roo are 41 and 30 individuals per square kilometer respectively (INEGI 2015). In Cuba, the population density in Pinar del Río province is very low compared to provinces like Havana. The coastal municipalities of María La Gorda have a total population of 588,272 inhabitants (ONEI 2016). Densities in Havana province exceed 2,900 individuals per square kilometer.

Figure 21. Population density by counties and municipalities.

From Yoskowitz et al. (2013).

In the United States, the coastal population of the five Gulf States is projected to increase from 44.2 million in 1995 to 61.4 million in 2025. This increase will significantly affect the natural infrastructure of the GOM and potentially stress already overburdened governance structures charged with meeting the demands of a growing population while also assuring the health and productivity of the region.

According to the "Human Development Report" (2011), at country level, Cuba is ranked fifty-first and Mexico is ranked fifty-eight; both are within the "High Human Development" group. The United States is ranked fourth and is within the "Very High Human Development" group. However, the GOM is not a homogeneous region and inside each state and country it is possible to find varying levels of quality of life including educational attainment (Figure 22).

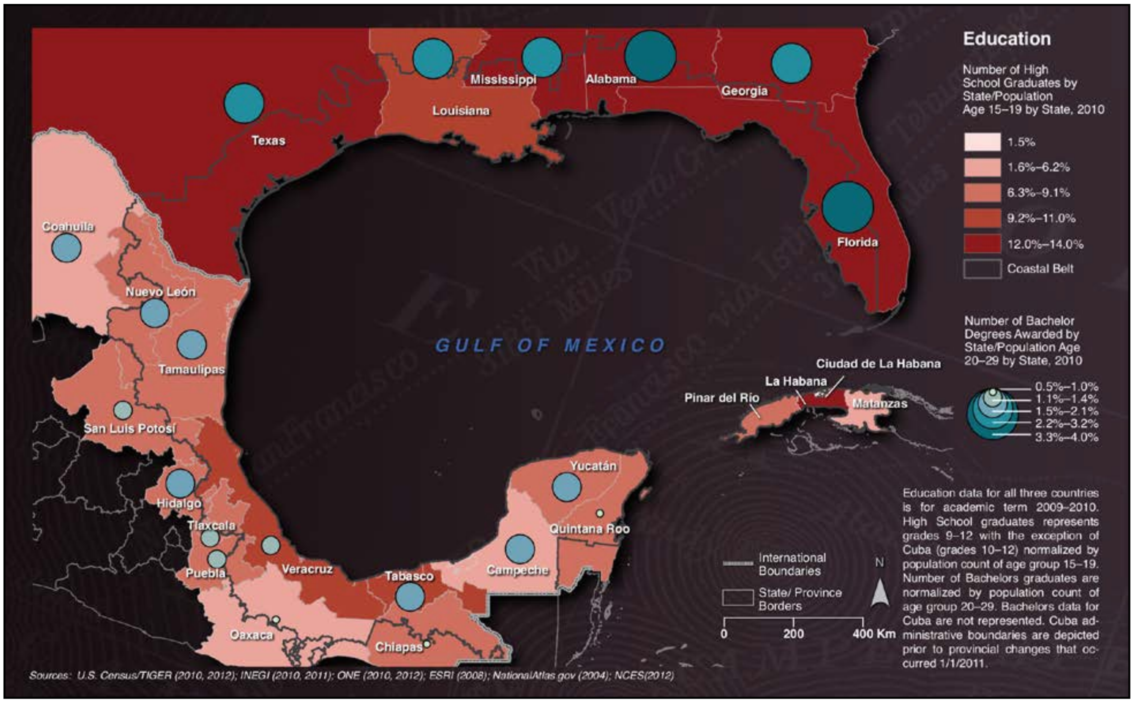

Figure 22. Educational attainment statistics.

From Yoskowitz et al. (2013).

1.2.7.3.2 Fisheries

Commercial, artisanal, and subsistence fishing are an important part of life in the GOM (Figure 23). From the coast of Louisiana to the lagoons of Veracruz and the mangroves of Cuba, the attachment to the sea for sustenance is universal. In the United States, red snapper (*Lutjanus campechanus*) is one of the most commercially and recreationally valuable fisheries, with reported landings of 8,598 thousand pounds in 2015. Mullets (family Mugillidae) are also harvested by commercial and recreational sectors showing captures exceeding 11,600 thousand pounds in the same year (NMFS 2015). In Cuba, lobsters (*Panulirus argus*) provide the largest contribution to commercial landings, followed by thread herring (*Opisthonema oglinum*), mangrove oyster (*Crassostrea rhizophorae*), and lane snapper (*Lutjanus synagris*) (Baisre 2017).

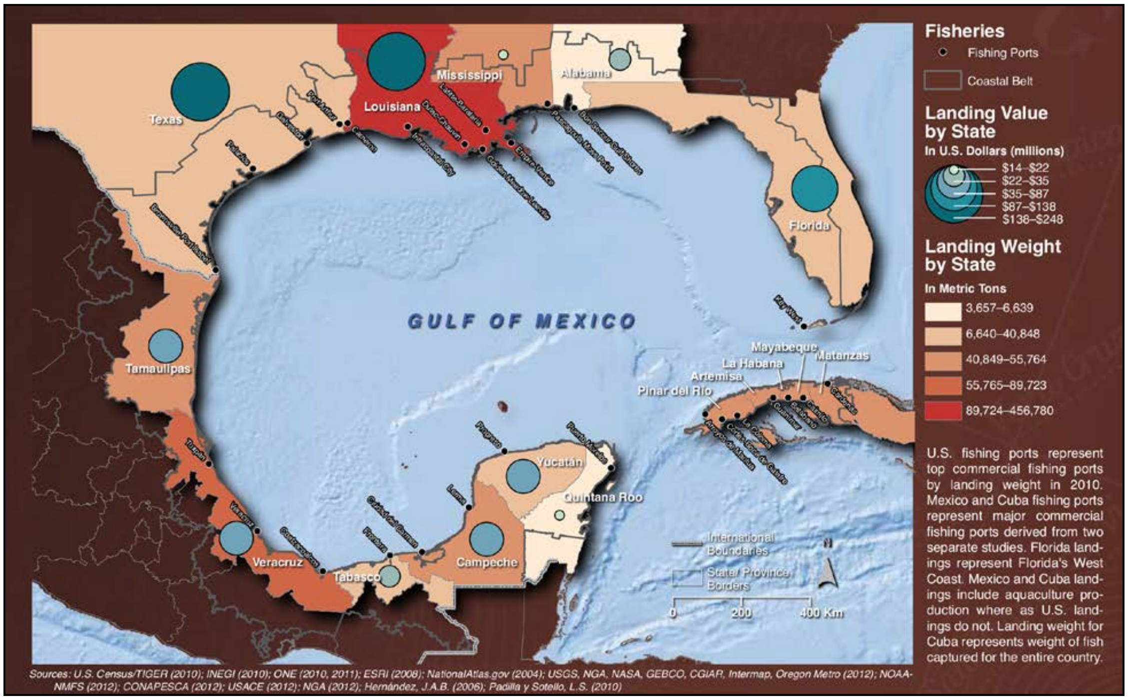

Figure 23. Fisheries landings by state.

From Yoskowitz et al. (2013).

Yet, this important resource can be compromised and there exists a delicate balance between human activities that can influence the health of a system and human needs of that system. The fishery closures that took place after the DWH oil spill are one example of the interconnectedness of the economic interests and the ecosystem. At its maximum, the closed area to fishing occupied 37% of US GOM federal waters on 2 June 2010.

1.2.7.3.3 Transportation

The movement of people and commerce between the three countries in the region is an important element (Figure 24). For example, the north and south crossings of noncommercial vehicles in South Texas was 29.9 million in 2011. Commercial crossings of trucks and rail boxcars in the same region in 2011 amounted to 5.4 million. In 2015, Cuba imported $176 million USD in products—mainly agricultural—from the United States and $355 million USD in goods and services from Mexico (OEC 2018).

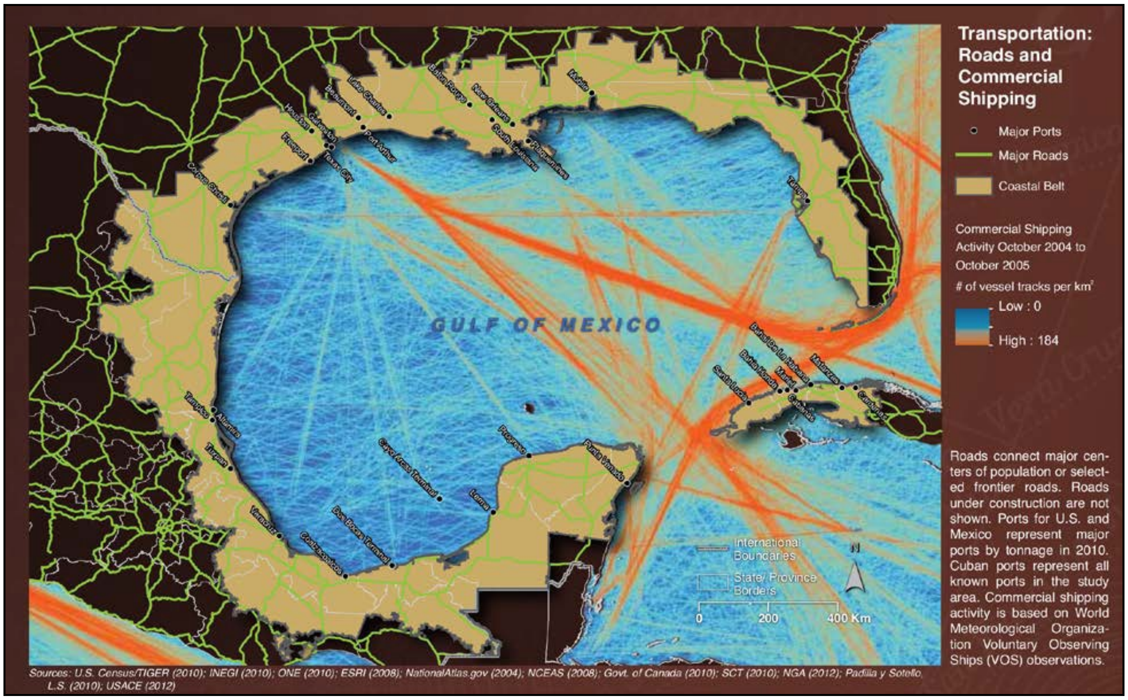

Figure 24. Transportation routes in the Gulf of Mexico region.

From Yoskowitz et al. (2013).

1.2.7.3.4 Protected Areas

Figure 25 represents designated terrestrial and MPAs on the international, national, and local levels as of September 2012 for United States–Mexico and 2010 for Cuba. MPAs in the United States that have been designated as gear-restricted areas, fishery closures, and reef fish stressed areas by the National Marine Fisheries Service have been excluded. Most Cuban protected areas on the local level are not shown, due to a lack of data availability.

Figure 25. Protected areas in the Gulf of Mexico region.

From Yoskowitz et al. (2013).

Much progress has been made in connecting protected areas amongst the three nations. In November of 2015, the United States and Cuba signed a memorandum of understanding to develop and coordinate a number of activities, including research and best management practices, between US sanctuaries (Flower Garden Banks and Florida Keys) and parks (Dry Tortugas and Biscayne) and Guanahacabibes National Park and offshore Bank of San Antonio in Cuba.

1.2.7.4 Conclusion

The GOM region is rich in cultural, biophysical, and socioeconomic diversity, and there is a lot that is similar between the bordering nations. Understanding the social and economic implications of natural resource management decisions for the GOM is critical in all three countries. Though the United States has begun to address its shortcomings on socioeconomic research and Cuba and Mexico are calling for similar efforts, there is still an opportunity to consider a regional approach to address some of the gaps. Specifically:

1. Conduct a regional (GOM) assessment of the “Coastal and Ocean Economy” to benchmark the impact and exposure of these sectors (fishing, tourism, oil and gas, shipping, etc.).
2. Identify commonalities in coastal and ocean resource management policy between the three countries as a starting place for regional coordination of resource management.
3. Develop a protocol to share socioeconomic data, information, and policies between the three countries that can potentially improve natural resource management.

1.2.7.5 References

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1.2.8 Oceanographic Observational Network Generating Scenarios of Possible Contingencies Related to the Exploration and Production of Hydrocarbons in the Mexican EEZ Gulf of Mexico Deep-Water Region

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1.2.8.1 Abstract

Here we present an overview of an unprecedented effort by several Mexican institutions, begun in 2015, to establish an oceanographic observation network of physical, geochemical, and ecological processes in the GOM, complemented with an important modeling effort. This project is planned to end during 2020 and will generate a large amount of information that will be used in future research of GOM oceanography and ecology. At the end of the project we will have a comprehensive set of observations and numerical models that will be able to generate oil spill scenarios and assess impacts and consequences of future hydrocarbon spills in the GOM.

1.2.8.2 Project Goals and Objectives

In March 2015, we began an unprecedented international collaboration to establish an oceanographic observation network in the GOM. The collaboration is led by CICESE and includes numerous institutions from Mexico (UNAM [ICMYL, CCA, IBT, IG], CINVESTAV-IPN, UABC, CIDESI, INECC-SEMARNAT, and Baja Innova), as well as collaborations from other countries (from the United States: WHOI, UCSB, RSMAS-UM, TAMUG; from France: LOCEAN, UPMC-Paris and LEGOS; and GEOMAR from Germany). Funding was provided by CONACYT-SENER Hydrocarbons Fund to the CIGOM consortium. The goal of the project is to implement and use many spatially fixed and mobile oceanographic observational platforms in real time, to perform oceanographic surveys covering different spatial and temporal scales to characterize the baseline conditions, and to typify hydrocarbon degradation processes with special emphasis on microbiology, to provide the necessary knowledge on the processes that control the GOM LME. These observational results will feed a comprehensive system of numerical and experimental simulations to reproduce the observational results. These efforts will improve our knowledge on the physics, biogeochemistry, and ecology of the GOM which will greatly aid in the generation of more realistic spill-scenarios and the assessment of their possible consequences based on scientific information.

Our overall objective is to strengthen scientific, technological and human capabilities of the Mexican oceanographic community, and to address the challenges associated with the production of hydrocarbons in the GOM, using interdisciplinary approaches and cutting-edge technologies.

This large project is articulated in five main activities:

1. Implementation of a network of continuous, fixed, and mobile observational platforms (oceanographic buoys, deep-sea moorings, submarine gliders, radar, and satellite images, multibeam mapping) to measure parameters and key variables to understand circulation processes and the biogeochemistry in deep and surface waters.
2. Execution of several oceanographic cruises in the GOM, the Florida Straits, and the western Caribbean Sea for the analysis and characterization of the main circulation, biogeochemical and ecological processes of this large ecosystem. These cruises will range from the deepwater region and into valuable coastal ecosystems that are susceptible to large oil spills, including

the identification of critical habitats for vertebrate species of ecological and economic importance.

3. The development of computational ocean community models that integrate the primary circulation, biogeochemical, and ecological processes to test and assess the evolution, fate, and possible effects of large hydrocarbons spills under different scenarios. This will include generation of numerical models of circulation and dispersion of hydrocarbons, the development of forecasting capacity, and constructing of maps of vulnerability.
4. The characterization of the physicochemical, photochemical, and native microflora degradation parameters on different hydrocarbon fractions through laboratory experiments, and the characterization of the metabolic pathways of metagenomes, with emphasis on those related to hydrocarbon degradation. All compiled information will be used for the development of empirical models that characterize the degradation of different hydrocarbon fractions at different depths for their integration in a general computational model of degradation of hydrocarbons in the GOM.
5. Analysis of the possible consequences of spill scenarios using an integrated approach, considering physical transport and dispersion processes in relation to fate and destination of oil components and their possible impacts on the ecosystems. This study focuses on the Perdido region and considers the importance of implementing an interdisciplinary strategy using mesocosm experiments and mapping of the coastal ecosystem's vulnerability.

1.2.8.3 Expected Results and Impact of the Project

This project is planned to end during 2020 and will generate a large amount of information that will be used in future research of GOM oceanography and ecology. At the end of the project we will have a comprehensive set of observations and numerical models that will be able to generate oil spill scenarios and assess impacts and consequences of future hydrocarbon spills in the GOM. This information will include:

- Physical, chemical, and biological variables to establish a baseline of the current state and natural variability of the GOM LME
- Observational platforms that produce data in real time and continuously using novel and cutting- edge technologies to measure critical variables that can be used in the event of a spill and, using numerical models, will allow the possible fate and behavior of a spill to be estimated or predicted
- Physical, biogeochemical, and hydrocarbon transport models that incorporate weathering processes and generate risk maps, arrival times, and impact estimates efficiently, taking into account the chemical characteristics of hydrocarbons and the location and depth of possible spills
- High-level training of technical personnel and scientists
- Transfer of knowledge and skills acquired during the project to the federal agencies so that the comprehensive network will continue to be developed and managed appropriately.

The ultimate goal of this project is to strengthen the human capacity and scientific and technological infrastructure of oceanography in Mexico to address the challenges and needs associated with the exploration and exploitation of hydrocarbons in deep waters of the GOM, using an interdisciplinary approach and implementing cutting edge technologies.

The project responds to a technological need identified by PEMEX's Exploration and Production (PEP) unit for the implementation of a network of oceanographic observations. These observations must be able to provide the data needed to explore various scenarios for contingencies related to exploration and production of hydrocarbons in deep waters of the GOM. This is an important contribution to informing mitigation procedures and operations in the case of a large-scale oil spill. It also focuses on the strategic demands that PEMEX defines in its “Strategic Technological Program (PET) 2013–2027”, including the characterization of natural hazards, hydrocarbons, and behavior of deepwater equipment and systems in addition to risk management and reliability in the deep waters of the GOM.

1.3 Invited Contributions

1.3.1 Studies of a Texas Naturalist in the Southern Gulf of Mexico

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1.3.1.1 Abstract

Fueled by the opportunity of a new and developing university, and his love for Mexico, its biodiversity, and people, John W. Tunnell, Jr., “Wes” to friends and colleagues, dedicated his career to teaching, research, and collaborations in Mexico. His extensive knowledge of the scientists, institutions, habitats, geography, and research issues in the southern GOM helped with the development of the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University where its benefactor instructed him to include Mexico and Cuba in the workings of the new institute in the early 2000s.

1.3.1.2 Early Work in Mexico

During my first visit in 1965, Mexico’s remoteness, beauty, and biodiversity enamored me. This short trip with my college major professor, Dr. Allan Chaney, to the remote beaches of Tamaulipas south of the Rio Grande to collect seashells and brine shrimp set the path for my career in marine biology. Inspired by this first trip, my wife and I toured central and western Mexico in 1967 for three weeks, exploring deserts, mountains, and coastal areas. Seeing the great natural diversity in Mexico and meeting many people on this second trip confirmed that, yes, I wanted to do research in Mexico and work with Mexican colleagues. Little did I know back then that my love of Mexico and her people would be so important and instrumental late in my career for the development of the Harte Research Institute for Gulf of Mexico Studies (HRI) and its connection with Mexico and studies in the southern Gulf. This was one of Ed Harte’s first requests, that we study the entire GOM, including the United States, Mexico, and Cuba, not just the northern Gulf offshore of the United States. This short paper tells the story of my initial involvement in Mexico, my growing connections, involvement, and research there, and ultimately, connecting HRI with scientists and institutions of the southern Gulf.

Following my MS thesis project studying mollusks on a small submerged bank off Padre Island using SCUBA diving as a research tool, I decided to expand that work onto the coral reefs of Mexico. Early in my PhD studies in 1972, I did a reconnaissance trip to the State of Veracruz to determine access and the viability of these coral reef studies, and I visited the Universidad Nacional Autónoma de Mexico (UNAM) in Mexico City to meet marine scientists who studied the biodiversity of the GOM. Subsequently, I met Dr. Ernesto Chávez, a marine ecologist who studied coral reefs and who assisted me in obtaining my first permit to study in Mexico in 1973. This introduction and connection started a lifelong friendship and collaboration on many future projects.

My PhD dissertation project on the ecology and distribution of mollusks of northern and southern Veracruz coral reefs (Tunnell 1974) opened a door for me so start a graduate class in coral reef ecology. Two years after I arrived at my first university position at Texas A&I University at Corpus Christi (now Texas A&M University-Corpus Christi or TAMUCC), I began offering this class in June each summer (Figure 26). From 1976 to 1993 I taught the class on the Veracruz reefs (1976–1977 on Lobos Reef in the north and 1978–1993 on Enmedio Reef in the south). Some MS students returned on multiple trips to these reefs to do their thesis projects (Roberts 1981; Allen 1982; Henkel 1982; White 1982; Nelson 1991; Choucair 1992; Ricono 1998), and one did his PhD dissertation project (Lehman and Tunnell 1992; Lehman 1993). Our early studies on these reefs were qualitative assessments of what species lived there, and later studies involved quantitative analysis of reef organisms and coral cover. Some MS students also published their research (Nelson et al. 1988; Tunnell and Nelson 1989). In addition to these student studies, I published several papers about our work there (Tunnell 1988, 1993; Chávez and Tunnell 1993; Tunnell and Deslarzes 1996; Lang et al. 1998). In 1994, I transferred the Coral Reef Ecology class to the State of Quintana Roo, outside of the GOM, where 12 more students did their MS thesis projects.

Figure 26. Coral Reef Ecology class on the Veracruz reefs.

Students heading out to Lobos Reef, June 1976.

In addition to the Coral Reef Ecology class, I took my Estuarine Biology class to La Pesca, Tamaulipas, each spring, and I took my Biology of the Mollusca class to various sites along the shoreline of the State of Veracruz, including rocky shores, sandy beaches, and coral reefs. Sometimes, separate trips were made to the rocky shores of Veracruz for study (Wiley et al. 1982; Hicks and Tunnell 1995; Alvarado 1996).

The studies in Tamaulipas, as well as coastal ecology studies in South Texas, on the Laguna Madre led to my first book project. This project and eventual book, *The Laguna Madre of Texas and Tamaulipas* (Tunnell and Judd 2002; Figure 27), funded by The Nature Conservancy, led to our first book series at TAMUCC (Gulf Coast Books at Texas A&M University Press). I worked with my colleagues in Mexico to get the latest information about the lagoon in Tamaulipas, and I wrote six of the chapters within the book, some with other colleagues. As a follow up to this work, I participated in a major collaborative work with other Mexican colleagues on transboundary conservation by writing a chapter on the Laguna Madre in a large, colorful coffee table book (Tunnell and Álvarez 2005).

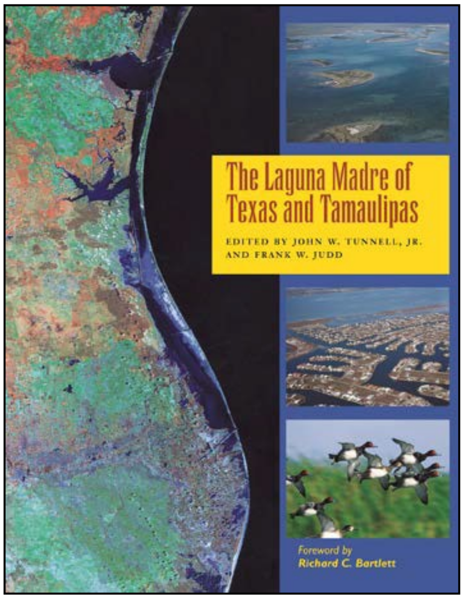

Figure 27. Cover of *The Laguna Madre of Texas and Tamaulipas*.

Edited by Wes Tunnell and Frank Judd, with contributions by Kim Withers, Elizabeth Smith and others, this book was published in 2002 by Texas A&M Press. A second, updated edition is currently in the works. Photo by Wes Tunnell.

During the academic year of 1985–1986, I received a Fulbright Scholar Award to move to Mérida, Yucatán, to study the mollusks and coral reefs around the Yucatan Peninsula (Hicks et al. 2001; Tunnell, Barrera et al. 2007). My home institution during this research period was CINVESTAV-Mérida, where Ernesto Chávez was chairman of the Marine Resources Department. It was at this time that Ernesto and I decided to prepare a book together someday on the coral reefs of the southern Gulf of Mexico (Tunnell, Chávez, et al. 2007). I also had the opportunity to study seabirds and their nesting habits on the Campeche Bank coral reef islands during this period (Tunnell and Chapman 1988; Tunnell and Chapman 2000; Figure 28) It was during this Fulbright year that I made many new contacts and colleagues in the southern GOM, who would aid and positively influence future projects and/or programs.

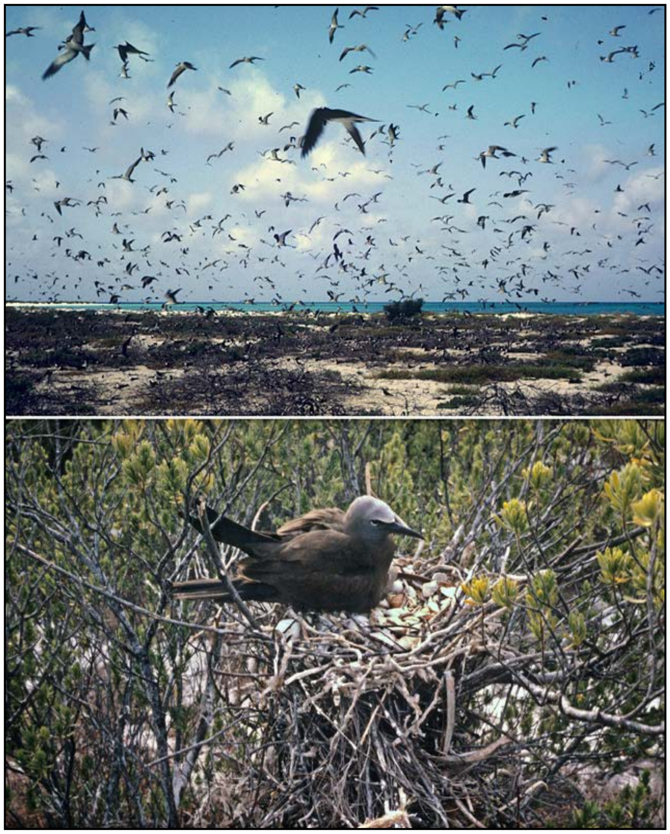

Figure 28. Colonial-nesting seabirds on Isla Pérez, Alacrán Reef, July 1986.

Top: Over 25,000 Sooty terns have been observed nesting on the island during the breeding season. Bottom: Brown Noddy on her nest. Photos by Wes Tunnell.

1.3.1.3 Collaborations with Mexican Researchers and Institutions, Under the Auspices of HRI

During the early development of HRI for Gulf of Mexico Studies, we had the opportunity to greatly broaden and expand our reach and cooperativeness with Mexico and Mexican scientists. Some Mexicans became important advisors on our HRI Advisory Council, and others facilitated our work in the southern Gulf. In December 2001, we invited scientists from Mexico, Cuba, and the United States to TAMUCC to discuss HRI's focus and direction with our new Advisory Council (Tunnell 2002). This Gulf-wide inclusiveness led to subsequent HRI Advisory Council meetings in Veracruz, Monterrey, and Havana, and the inclusion of leading Mexicans and Cubans on the HRI Advisory Council. It also led to the development of GulfBase, a research and resource database for all Gulf scientists, students, agency personnel, and the interested public.

Dr. Admiral Alberto Vázquez de la Cerda, a physical oceanographer and former admiral of the Mexican Navy's oceanographic program, arranged for us to use Mexico's Naval Oceanographic Ship, the B/O *Antares*, for a NOAA-HRI Sustainable Seas Expedition to the Veracruz Reefs in September 2002, where we used the mini-submersibles Deep Worker and Deep Rover (Tunnell, Earle, et al. 2007; Figure 29).

During this research cruise, we were able to see the mass spawning of the Veracruz reef corals and document it for science for the first time (Beaver et al. 2004) and to quantitatively compare six coral reefs in the region (Jones et al. 2008).

Figure 29. Wes Tunnell in the mini-submersible *Deep Worker*.

Tunnell piloted the mini-submersible during a NOAA-HRI Sustainable Seas expedition to the Veracruz coral reefs aboard the B/O *Antares,* Mexico's Naval Oceanographic Ship. This was a joint expedition between scientists from Mexico and the United States and documented the mass spawning on the Veracruz reefs for the first time. Photo by Carl Beaver.

Also during the early development of HRI, Dr. Ernesto Chávez came to HRI for one year as a visiting scientist (2002–2003). During this time, we began in earnest to finalize our book *Coral Reefs of the Southern Gulf of Mexico* (Tunnell, Chávez, et al. 2007; Figure 30), where I wrote or co-wrote seven chapters. The thesis projects mentioned above from the Veracruz reefs were instrumental in establishing the known biodiversity of the southern Gulf coral reefs and islands (Tunnell, Barrera, et al. 2007).

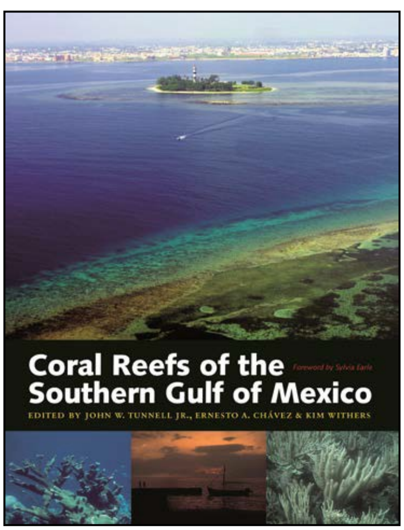

Figure 30. Cover of *Coral Reefs of the Southern Gulf of Mexico*.

This book was edited by Wes Tunnell, Ernesto Chávez, and Kim Withers, with contributions by Guillermo Horta-Puga, David Liddell, and Carl Beaver, among others. The English version was published by Texas A&M Press in 2007; the Spanish version was published in 2010 by the Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, Baja California Sur, Mexico. Photo by Wes Tunnell.

In 2004, I participated in a very important conference in Veracruz, Mexico entitled "Environmental Diagnosis of the Gulf of Mexico" (Diagnóstico Ambiental del Golfo de Mexico), which was sponsored by the National Institute of Ecology (INE) in Mexico City. Most leading marine scientists studying the southern GOM participated in this conference and wrote papers for the two-volume proceedings (Caso et al. 2005). Because this was the first summarization of all marine science of the southern GOM, I worked with INE to have it translated into English, and then it was digitally published by HRI (Withers and Nipper 2008; Tunnell 2008a). I presented a paper on HRI's new collaborative work in the GOM with the United States, Mexico, and Cuba which was published in both the Spanish version (Tunnell et al. 2005) and the English version (Tunnell et al. 2008).

When HRI opened its building in 2005 and began hiring endowed chair positions, I helped develop a second book series with TAMU Press, the Harte Research Institute for Gulf of Mexico series, which began in 2007. The first volume, which was a project of HRI that began in 2002, was a large book on the total biodiversity (15,419 species in 79 chapters) of the GOM (Felder and Camp 2009). This large project involved 140 authors/taxonomists from 80 institutions in 15 different countries. Mexico had 18 authors in the volume. I coauthored the Foreword to this volume (Tunnell et al. 2009), as well as the Introduction (Felder et al. 2009), one of the mollusk chapters ("Mollusca: Introduction," Moretzsohn et al. 2009), and the brachiopod chapter (Santagata and Tunnell 2009). Volume 2 of the Gulf of Mexico book series *Ocean and Coastal Economy* (Cato 2008) did not have any Mexican scientist participation, but Volume 3, *Geology* (Buster and Holmes 2011) and Volume 4, *Ecosystem-Based Management* (Day and Yáñez- Arancibia 2013) had numerous southern Gulf authors and topics. I wrote or cowrote three chapters in these latter volumes, one on southern Gulf coral reef geology (Lidell and Tunnell 2011), one on southern Gulf coral reef impacts and management (Tunnell and Chávez 2013), and one on ecosystem-based management in the Laguna Madre (Smith et al. 2013). Volume 5, *Chemical Oceanography*, and Volume 6, *Nautical Archaeology*, which are now underway will have numerous southern GOM, Mexican authors.

In 2006, HRI sponsored the first "State of the Gulf of Mexico Summit in Corpus Christi." This three-day conference included about 450 invited scientists and managers from the United States and Mexico, and special guest speakers were the governors of the states of Texas, Tamaulipas, and Veracruz, strongly showing our desire to work with the entire Gulf community (Tunnell and Dokken 2006). Subsequent summits, held in 2011, 2014, and 2017 in Houston, have become the "go-to" place for leaders of GOM science, policy, and management. Each of these meetings has engaged an increasing number of Mexican scientists, and the 2017 meeting included a significant contingent of Cubans.

In 2009, I became a member of the Steering Committee for the "Integrated Assessment and Management of the Gulf of Mexico Large Marine Ecosystem." This project, funded by the Global Environment Facility (GEF) of the World Bank, is managed and implemented by UNIDO (United Nations Industrial Development Organization). This program's multiple meetings in Mexico over the years allowed me to develop strong relationships with numerous Mexican scientists in academia and government, many of whom now cooperate and collaborate with HRI.

Although our first HRI cooperative agreement was in 2003 with the non-governmental organization Fondo Mexicano para la Conservación de la Naturaleza, most of the others were with academic institutions in the southern Gulf between 2008 and 2016: Universidad Veracruzana, CINVESTAV-Mérida, Universidad Autónoma de Yucatán, Universidad Autónoma de Campeche, Universidad Autonóma de Tabasco, and Universidad Nacional Autónoma de México-Sisal. These cooperativeagreements allowed HRI to be involved cooperatively and collaboratively with all of the main southern Gulf universities conducting studies in marine science.

Along with these cooperative agreements, strengthening our ties to Mexico, I became a guest editor for a special issue of the marine science journal *Gulf of Mexico Science* to produce a history of all marine labs around the GOM (Tunnell and Crozier 2010). The special issue (Volume 28, Numbers 1–2) was issued in 2010 and included 22 articles on marine labs around the Gulf, including one from Cuba and four from Mexico. These articles revealed insight into the Mexican southern Gulf labs and opened the opportunity for cooperation and collaboration among Gulf scientists.

During this same timeframe, I worked with several HRI chairs, numerous US colleagues, and a number of Mexican scientists to consider and push the idea of a network of MPAs around the GOM (Tunnell 2008b; Tunnell 2011). This concept, initially called "Islands in the Stream" and later called "Beyond the Horizon", was to protect ecological connectivity of some established and some new MPAs around the Gulf in the United States, Mexico, and Cuba. Unfortunately, although there was widespread interest form many organizations, institutions, and agencies, the project did not gain traction. However, one of our PhD students, Harriet Nash, carried the project forward by doing her dissertation and several papers on the policy and governance of such a network (Nash 2013; Nash and McLaughlin 2012, 2014).

In 2013, I helped C-IMAGE (Center for Integrated Modeling and Analysis of Gulf Ecosystems) connect with Mexican scientists at UNAM and develop a three-year proposal (2015–2017) that was funded to study the long-term impacts of the Ixtoc I oil spill in the southern GOM in comparison to the DWH oil spill in the northern Gulf. Old collaborations from CINVESTAV and UNAM allowed this new and large research program to develop and engage five HRI endowed chairs. So far I have published one paper with C-IMAGE II colleagues (Sun et al. 2015), and several others are currently submitted or in progress.

Last, my long-time focus on GOM biodiversity, southern GOM coral reefs, and the Gulf ecosystem, all with Mexican colleagues, led to three significant, recent research focuses/summaries on Gulf biodiversity (Fautin et al. 2010; Ellis et al. 2011; Miloslavich et al. 2016), status and trends of Gulf and Caribbean coral reefs (Jackson et al. 2014), and the Gulf ecosystem as a part of the World Ocean Assessment (Rice et al. 2016). From these latter works, several lines of research should be considered:

- Focus on southern GOM biodiversity and deep GOM biodiversity. Many specimens/species reside in the national collections of UNAM, so collaborations with or funding to scientists there would be the cheapest place to start.
- An annual environmental monitoring program for the coral reefs of Veracruz (southwestern Gulf) and the Campeche Bank (southeastern Gulf) would give scientists and managers of the Florida Keys National Marine Sanctuary and Flower Gardens National Marine Sanctuary a southern Gulf comparison on the "health" of all GOM coral reef areas.
- Coordination of researchers and agencies/institutions between the United States and Mexico on selected environmental stressors and issues that impact Gulf waters in both countries, such as harmful algal blooms, invasive species, threatened and endangered species, hypoxic zones, habitat destruction, coastal development, estuarine eutrophication, overfishing, marine debris, oil spills and other pollution, and climate change.

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1.3.2 Improving Cooperation in US/Mexican Marine Science to Better Manage Offshore Hydrocarbon Activities in the Gulf of Mexico

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1.3.2.1 Abstract

Energy reforms that have spurred rapidly increasing exploration activities in Mexico, especially in areas near the United States-Mexico maritime boundary in the Gulf of Mexico (GOM), with a ramping up of offshore production activity proposed by the Trump Administration in US waters, make it imperative that the two nations begin to work more closely together to manage hydrocarbon resource development. In light of the evolving regulatory regime in Mexico and the potential transboundary impacts associated with increased offshore oil and gas activity in the GOM in the next decade, it is important for scientists and regulators from both countries to engage in a process of coordinating their activities. These efforts should include prioritizing research needs; conducting joint, or at least coordinated cruises; and finding methods to effectively share and analyze collected scientific data. If the two nations fail to cooperate fully, management efforts will not occur or will suffer from redundancy and duplication of effort. A better understanding of the environmental regulatory requirements in Mexico should also be promoted so that scientists from industry, government, academia, and non-governmental organizations can begin to plan for collection and monitoring activities and prioritize the type of information that would best meet Mexico's needs. A significant amount of funded science in the GOM in coming years will address the need for complying with each nation's regulatory and environmental permitting mandates. Bringing both nations' regulatory and science communities together to determine the best path forward to accomplish this important task should be a high priority.

1.3.2.2 The Need for Transboundary Cooperation in the Era of Deepwater Oil Production

An essential feature of governing offshore energy development is obtaining scientific information needed to effectively assess, predict, and manage potential impacts from hydrocarbon exploration and production activities. There are strong reasons for United States and Mexican scientists to work towards maximizing cooperative efforts in marine environmental research and data collection. Increased production is likely in the GOM during the next five to ten years. In fact, there is probably nowhere in the world where targeted scientific information is more crucial than in the GOM. Today, with more than 3,500 existing offshore structures and 33,000 miles of pipelines, the GOM is one of the world's most important and intensively developed offshore production areas. Mexico and the United States have exploited hydrocarbons in their respective portions of the GOM for decades. Unlike earlier production, which was primarily in shallow nearshore areas, technological advances have pushed current production further out onto the deeper continental shelf to the point that of the more than 567 million barrels of oil produced in the US GOM in 2009, 80% took place in depths of 1,000 feet or deeper (Richards 2011). We have far less scientific knowledge about the deeper and more remote areas of the GOM than the shallower areas closer to shore.

Accelerating this trend toward deepwater production is Mexico's recent decision to reform its energy industry. On 5 December 2016, Mexico completed its first deepwater oil auction in the GOM. This ended a 75-year monopoly held by state-owned Petróleos Mexicanos (PEMEX), and opened Mexico's offshore areas, with their huge hydrocarbon potential, to foreign investment. By all measures, the auction was highly successful with international oil giants such as France's Total, the China National Offshore Oil Corporation, and Exxon Mobil and Chevron of the US winning bids on exploratory blocks that are estimated to contain as much as 11 billion barrels of oil and natural gas (Malkin and Krauss 2016). Mexico subsequently held several successful actions. With the election of Andrés Manuel López Obrador on July 1, 2018; auctions have been postponed until 2021.

The rapidly increasing exploration activities in Mexico, especially in areas near the US-Mexico maritime boundary, coupled with a ramping up of offshore production activity proposed by the Trump Administration in US waters make it imperative that the two nations begin to work more closely together to manage hydrocarbon resource development in the GOM. Collaboration in collecting, analyzing, and storing marine scientific information is essential to support both governments' responsibilities in carrying out their regulatory and management duties.

Mexico and the United States recognize that the GOM is one large marine ecosystem and that environmental damage to one portion of the Gulf can have transboundary consequences. A number of bilateral cooperative agreements to more effectively manage oil and gas development in the GOM have been negotiated. For example, the MEXUS agreement controls how the two nations respond to transboundary oil spills (US Coast Guard 2000). The 2012 "Agreement on the Exploitation of Transboundary Hydrocarbon Resources in the Gulf of Mexico" creates a legal framework that allows the two nations to jointly exploit the shared oil and gas resources that straddle the maritime boundary and promotes the creation of common environmental standards (US Department of State 2012). Most recently, the American Petroleum Institute (API), which represents the US oil and gas industry, reached an agreement with the National Agency for Industrial Safety and Environmental Protection of the Hydrocarbons Sector (ASEA), Mexico's oil and gas regulatory agency, to assure that ASEA will be able to include API recommended environmental and safety standards and practices into its own regulations.

Bilateral efforts, such as these, which seek to promote more efficient and safe methods of managing oil exploration and production, are extremely important as Mexico continues to open its offshore areas to development in the future. However, all are dependent on having a strong understanding of the state of marine and coastal science in the southern GOM. In this regard, it is important to note, based on the information from the plenary sessions of the GOMWIR, and the discussions within and between members of the GOMWIR working groups, that our scientific knowledge of the marine and coastal environments in Mexico's portion of the Gulf is less robust than in the US portion. One of the goals of GOMWIR is to determine where gaps exist in this scientific knowledge and how best to prioritize future collaborative research efforts.

In addition, both nations require scientific information from government and non-government marine scientists to carry out specific legislative mandates within their own territories. For example, the US Bureau of Energy Management (BOEM), tasked with managing development of the nation's offshore resources, has an Environmental Studies Program that informs its offshore leasing activities. This program's mandate is derived from provisions of the National Environmental Policy Act (NEPA) and the Outer Continental Shelf Lands Act (OCSLA). OCSLA Section 20 establishes three primary goals:

1. To establish the information needed for assessment and management of environmental impacts on the human, marine, and coastal environments of the OCS and the potentially affected coastal areas;
2. To predict impacts on the marine biota which may result from chronic, low-level pollution or large spills associated with OCS production, from drilling fluids and cuttings discharges, pipeline emplacement, or onshore facilities; and
3. To monitor human, marine, and coastal environments to provide time series and data trend information for identification of significant changes in the quality and productivity of these environments, and to identify the causes of these changes.

Information from this program is also used to meet additional legislative mandates to protect the marine environment such as those in the Endangered Species Act, Marine Mammal Protection Act, Clean Air Act, Magnuson-Stevens Fishery Conservation and Management Act, Historic Preservation Act, and other federal statutes. Without adequate scientific information, BOEM would have a difficult time conducting environmental reviews, including NEPA analyses, and producing compliance documents required from a whole host of applicable environmental statutes.

Mexico has similar legislative mandates and priorities. One of the greatest challenges posed by the rapid pace of Mexico’s energy reforms is developing a fully functioning regulatory regime to deal with potential environmental impacts of its growing offshore hydrocarbon activities. ASEA has been authorized to establish regulations regarding the conditions and actions that will be taken for any environmental damage that occurs. Article 3 of the Internal Regulations of ASEA establishes that the executive director of the agency will have the authority to “coordinate the studies of economic assessment of environmental externalities and risks associated with the facilities, activities, and operations of the sector based on a methodology which takes best international practices into account” (Serra 2017).

While ASEA is still developing the expertise and effective capacity to regulate and monitor all of the exploration and production projects that may be developed in Mexican waters, it has made great strides in promulgating regulations and guides for its work in its short history. With the likelihood of increasing activities in the Mexican Gulf of Mexico, there will be a strong need for a broad spectrum of scientific research and monitoring capabilities to address these regulatory requirements.

1.3.2.3 Conclusions

In light of the rapidly evolving regulatory regime in Mexico and the potential transboundary impacts associated with increased offshore oil and gas activity in the GOM in the next decade, it is important for scientists and regulators from both countries to engage in a process of coordinating their activities. These efforts should include prioritizing research needs; conducting joint, or at least coordinated, cruises; and finding methods to effectively share and analyze collected scientific data. If the two nations fail to cooperate fully, management efforts will not occur or will suffer from redundancy and duplication of effort. A better understanding of the environmental regulatory requirements in Mexico should also be promoted so that scientists from industry, government, academic, and NGOs can begin to plan for collection and monitoring activities and prioritize the type of information that would best meet Mexico’s needs. Funding sources for priority research needs as well as support for training future scientists from both nations should be located and encouraged.

A future workshop beyond GOMWIR that serves as a bridge to bring together the scientific needs of mission-driven agencies, such as ASEA and BOEM, with the expertise of working marine scientists from both nations would be extremely beneficial. A significant amount of funded science in the GOM in coming years will address the need of complying with each nation’s regulatory and environmental permitting mandates. Bringing both nations’ regulatory and science communities together to determine the best path forward to accomplish this important task should be a high priority.

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1.3.3 Ocean Acidification Studies in the Gulf of Mexico: Current Status and Future Research Needs

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1.3.3.1 Abstract

This review summarizes recent research on ocean acidification (OA) in the broad GOM region. Current understanding focuses mostly on the US side of open waters, continental shelves, and estuaries. There has not been a systematic examination of open Gulf acidification to date. However, recent large-scale surveys in the GOM may shed light on decadal variability of the carbonate system. Coastal OA studies mostly examined eutrophication-enhanced acidification through spatially coupled surface production and respiration at depth. In terms of estuarine acidification, hydrological condition change was used to explain gradual decrease of both total alkalinity and pH in northwestern GOM estuaries, though estuarine carbonate chemistry in other areas has not been documented. In comparison to the US side of the research, there are relatively few studies relevant to OA in the southern GOM. Given the similar anthropogenic stressors in northern GOM such as eutrophication but more prominent coral reef presence in the southern GOM, it is imperative to examine how the seawater carbonate chemistry changes under both natural and impacted conditions and how these changes affect critical habitats. International and multidisciplinary collaborations may be needed to bring the expertise in the pan-GOM countries together for future investigations and synthesis.

1.3.3.2 Background

Since the Industrial Revolution, human beings have generated an enormous amount of carbon dioxide (CO_2) through fossil fuel burning, cement production, deforestation, and land use changes (IPCC 2013). Among the estimated 600±70 Gt-C (1 Gt-C = 10^{12} g-C) in the form of CO_2 released during the period of 1750-2015, ~43% (260±5 GtC) has accumulated in the atmosphere. Both the land and the ocean take up about an equal share of the rest of the released carbon (~28% or 165±70 Gt-C and ~29% or 175±20 Gt-C) (Le Quéré et al., 2016). Because every one part per million (ppm) CO_2 concentration increase in the atmosphere is equivalent to the accumulation of 2.12 Gt-C (or 7.77 Gt CO_2) (Ballantyne et al. 2012), then the total atmospheric 260 Gt-C accumulation since the industrial revolution is translated to 123 ppm increase in CO_2 concentration, which is added to the ~280 ppm CO_2 before the industrial revolution and yields the current 400+ ppm atmospheric CO_2 level.

The ocean as a huge acid-base buffer system has absorbed ~29% human produced CO_2 so far (Sabine et al. 2004; Le Quéré et al. 2016). Oceanic uptake of CO_2 has effectively dampened CO_2 increase in the atmosphere. However, because CO_2 is a reactive gas, upon dissolution in seawater, a series of reactions occur:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + CO_3^{2-} \rightarrow 2HCO_3^-$$

The weak acid produced by CO_2 dissolution will titrate carbonate ion (CO_3^{2-}) in the seawater and reduce its concentration and at the same time, increase proton concentration (or decrease in seawater pH), a process coined as "ocean acidification" or OA (Feely et al. 2004; Doney et al. 2009). Based on thermodynamics, carbonate ion concentration decrease leads to a decrease in carbonate mineral saturation states (Ω) because calcium ion (Ca^{2+}) concentration change is small across different ocean basins:

$$\Omega = [Ca^{2+}][CO_3^{2-}]/K_{sp}$$

Here K_{sp} is the solubility constant of $CaCO_3$ mineral. The saturation level Ω exerts fundamental control on the ability of calcifying organisms in producing $CaCO_3$ skeletons (for corals, coralline algae) or hard shells (shellfish) (Waldbusser et al. 2014).

Over the past two decades or so, studies on OA have ranged from characterizing the changes in seawater carbonate chemistry (Feely et al. 2004; Bates et al. 2013; Brewer 2013; Wanninkhof et al. 2015) to investigating biological and biogeochemical consequences of such changes (Kleypas et al. 1999; Orr et al. 2005; Hoegh-Guldberg et al. 2007; Iglesias-Rodríguez et al. 2008; Millero et al. 2009; Andersson and Gledhill 2013; Waldbusser et al. 2014). Nevertheless, numerous studies have examined seawater carbonate chemistry in the open ocean, other marginal seas, and coastal areas, yet there is substantially less information on GOM in peer-reviewed literature.

To review the status of OA studies in the GOM region, geographical zones, including the open GOM, coastal areas, and estuaries, will be separately discussed. Because the majority of available studies relevant to OA are focused on the northern and northwestern GOM, these areas will be reviewed while implications to the southern GOM will be inferred.

1.3.3.3 Status of OA Studies in the GOM

The GOM is a marginal sea. Marginal seas are often separated from the open ocean by geological features (sills or ridges). While the upper water columns above these sills on both sides of these geological features essentially have the same origin(s), deeper water exchanges between a marginal sea and its connected open ocean are always restricted (Liu et al. 2010). Below is a list of major marginal seas in the world:

- GOM connects with the northwestern Caribbean Sea through the Yucatan Sill (2,040 m) (Rivas et al. 2005)
- The Caribbean Sea connects with the North Atlantic Ocean through the Anegada-Jungfern, or AJ passage (1,815 m) (MacCready et al. 1999) and the Windward Passage (1,700 m) (Rivas et al. 2005)
- The South China Sea connects with the West Philippine Sea to the east through the Luzon Strait (2,200 m) and the Sulu Sea to the south through the Mindoro Strait (420 m) (Chen et al. 2006).
- The East/Japan Sea connects with the North Pacific through three shallow straits (~150 m; Park et al. 2006)
- The Sea of Okhotsk connects with the North Pacific through two deep straits the Kruzenshterna (1,990 m) and the Bussol (2,300 m; Wakatsuchi and Martin 1991)
- The Mediterranean Sea connects with the North Atlantic through the Gibraltar Strait (600 m; Huertas et al. 2009)

Because of the restricted connection, OA in the marginal seas will both carry the signals of the source waters and have imprints due to disparate biogeochemical processes occurring within themselves.

1.3.3.3.1 Open GOM Acidification

GOM open water surface circulation is influenced by the Loop Current that originates from the Caribbean Sea and passes through the Yucatan Channel as well as the spinoff eddies of the Loop Current (Sturges 1993). A modeling study suggested that the strength of the Loop Current may decline by 20–25% during the twenty-first century, leading to reduced warming in the northern GOM (Liu et al. 2012).

To date, few published studies examined open GOM carbonate chemistry and the only available studies focused on the northern and eastern GOM with the emphasis on the continental shelves (Wang et al. 2013; Wanninkhof et al. 2015). These studies are the outcomes of the only two large-scale coast wide expeditions that covered both the northern GOM coast and the US East Coast (GOMECC-1 and GOMECC-2). The third GOMECC cruise took place on 18 July–21 August 2017, and the entire GOM from the shelf waters to the deep basin was examined across 10 transects, including two transects that covered both the Yucatan Channel and the Straits of Florida.

Available data suggest that the open GOM surface waters have relatively high aragonite saturation state (or Ω_{arag}). For example, in July 2007, Ω_{arag} was above 3 ($\Omega = 1$ indicate equilibrium condition) for all three transects that ran perpendicular to the coast (Texas, Louisiana, and West Florida) in the upper 50 m of water across almost the entire northern GOM (Wang et al. 2013). Similarly, based on cruise data collected in July 2012, Wanninkhof et al. (2015) showed that surface (<10 m) waters in the open GOM all have Ω_{arg} at the ~4 level and evaporation-precipitation controlled Ω_{arg} variations.

To the best of the author's knowledge, temporal variability of Ω_{arg} in the open waters of the GOM has not been broadly disseminated in the scientific literature. Although given that much of open GOM can be considered as oligotrophic because of low levels of nutrients (Biggs 1992; Xue et al. 2016), temperature probably plays an important role in regulating Ω_{arag} dynamics across the seasons. The temperature dependence of Ω_{arag} may be inferred from the similarly oligotrophic Flower Garden Banks region in the northwestern GOM near the shelf-slope break, where temperature was found to explain 70–80+% of Ω_{arag} variation (Ω_{arag} ranged 3.4–4.2) over the period of 2013–2016 (Hu et al. unpublished data; Johnston et al. 2016; Nuttall et al. 2017). Furthermore, because of the oligotrophic nature of surface water in the open GOM with small primary productivity, it is likely that Ω_{arg} will decline following the continuing increase in atmospheric CO_2, at a rate similar to those observed in the Greater Caribbean region (Gledhill et al. 2008).

1.3.3.3.2 GOM Coastal Waters

Compared with the changes in carbonate chemistry in relatively oligotrophic open GOM surface water, coastal waters in the GOM are much more complex because of significant terrestrial influences. The most highly studied region around the GOM coast is the Louisiana shelf, where copious amount of anthropogenic nutrients are delivered into shelf waters via the Atchafalaya-Mississippi River system (MARS) (Turner and Rabalais 1994; Rabalais et al. 2002). In addition, due to changes in agricultural practice (e.g., application of lime in farmland to combat soil acidification) and the overall increase in continental weathering, riverine alkalinity export in this region has been increasing based on a century-long dataset (Raymond and Cole 2003; Raymond et al. 2008). Combining both increasing alkalinity export and nutrient-enhanced primary production, surface waters of the eutrophic coastal zones may have been experiencing so-called "basification" (Duarte et al. 2013; Nixon et al. 2015), instead of commonly observed acidification in the open ocean. *In situ* coastal water CO_2 partial pressure observations in the northern GOM near the coast of Mississippi also appear to support the basification notion because surface water CO_2 level shows an apparent decreasing trend over the past decade.

Contrary to the enhanced production-led pH increase in the surface water, subsurface and bottom waters accumulate substantial respiration-produced CO_2, and this CO_2 signal is especially strong when the water column stratification occurs in summer, when surface water becomes less saline (due to river water input) and warmer (due to surface heating). Buildup of CO_2 accompanies significant reduction of dissolved oxygen level as microbes respire the surface-produced organic matter, and when dissolved oxygen is below 2 mg L^{-1} it is termed hypoxic (Rabalais et al. 2001). As a result of aerobic respiration, bottom waters on the northern GOM continental shelf can experience substantial acidification symptoms as represented by reductions in both pH (Figure 31) and Ω_{arag}, and further acidification will occur because of continuing acidification of the open ocean water that supplies this shelf area if the eutrophication condition is not improved (Cai et al. 2011). A recent study suggested that not only water column respiration, but benthic respiration also contributes to bottom water acidification (Hu et al. 2017). In addition, the spatially-coupled pH variation as a result of enhanced nutrient cycling (i.e., pH increase in the surface (nutrient consumption) and decrease in the bottom (nutrient regeneration)) far outweighs that caused by either the river chemistry change or temperature change on decade to century time scales (Hu et al. 2017). Furthermore, because of lower solubility of CO_2 in the warm GOM waters compared with the cooler US West Coast, higher buffer capacity in the GOM to begin with, GOM waters will reach hypercapnic conditions (pCO_2 partial pressure greater than 1,000 µatm) at oxygen concentration of 170 µmol kg^{-1} toward the end of this century, and the West Coast will reach hypercapnia when oxygen is 260 µmol kg^{-1} (Feely et al. 2018).

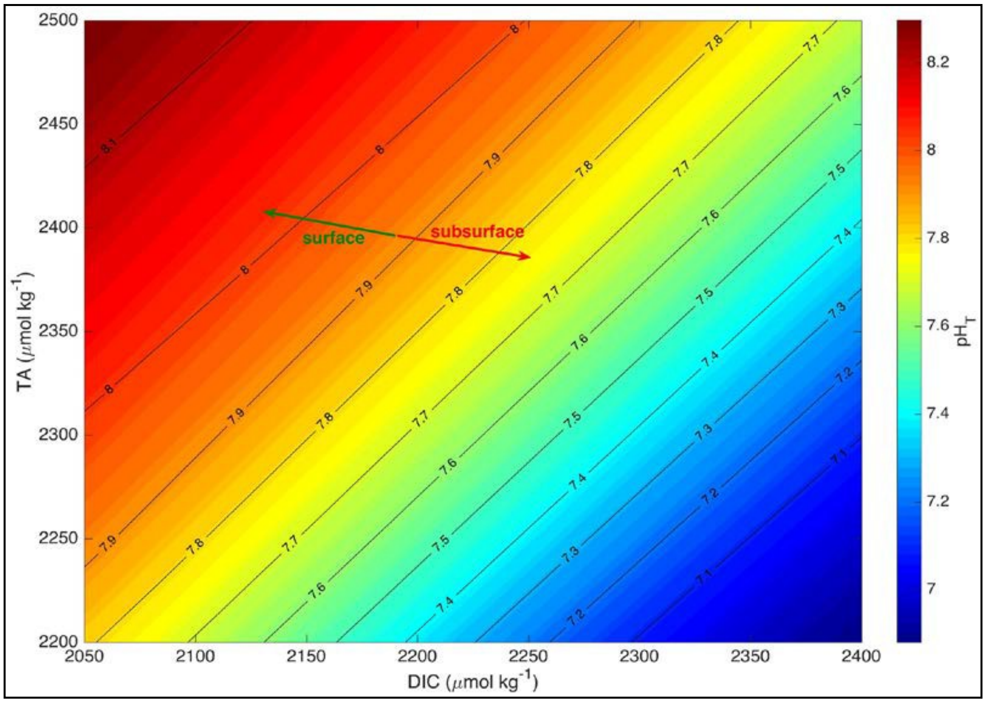

Figure 31. A simulation of seawater pH as a function of alkalinity (TA) and total dissolved CO_2 (DIC).

The green arrow indicates surface water production that follows the Redfield stoichiometry, and the red arrow represents aerobic respiration. This calculation was done using the program CO2SYS (Pierrot et al. 2006) at 20˚C and salinity 35.

The northern GOM is not the only area that experiences bottom water hypoxia in the Gulf. Smaller rivers such as the Brazos River in the northwestern GOM can have disproportionally large discharge during wet seasons that are affected by large scale climate variability (Tolan 2007). Historically, high river discharge events are not uncommon and they have been recorded in the sediment in the adjacent continental shelf (Carlin and Dellapenna 2014). Similar to that in the northern GOM, extensive hypoxia can also occur because of high river discharge in this area (DiMarco et al. 2012). Therefore, bottom water acidification along with the occurrence of hypoxia is expected in this shelf area as well (i.e., northwestern GOM).

In addition to the modern marine-produced organic matter that drives microbial respiration, additional respiration signal using fossil carbon (oil and natural gas) has been noted in both natural settings (Aharon et al. 1992) and after human-caused oil spills (Kessler et al. 2011; Hu et al. 2016). Respiration of these organic compounds will also lead to the production of CO_2. However, there has been no actual field study that focuses on this issue anywhere in the world other than computer-based simulations (Boudreau et al. 2015). Admittedly, CO_2 production per unit oxygen consumption from fossil carbon remineralization is lower than that from marine and even terrestrial organic carbon, due to more reduced oxidation state of the former.

1.3.3.3.3 Acidification (or Dealkalization) of Estuaries

Because river end-members play an important role in controlling carbonate chemistry in an estuarine mixing zone (Salisbury et al. 2008; Hu and Cai 2013), rivers that have lower levels of total alkalinity result in a larger salinity range that have lower Ω_{arag} values. Therefore, estuaries that receive river waters with lower alkalinity levels potentially are subject to larger fluctuations in both pH and Ω_{arag}. The large river system in the middle of the northern GOM (MARS) has relatively high alkalinity levels (1,500–

3,000 µmol kg^{-1}; Hu et al. 2017), whereas the next two largest rivers in the United States (Mobile River and Apalachicola River) have only ~900±200 µmol kg^{-1} alkalinity (USGS). However, no systematic studies have been done in the northeastern GOM estuaries from the acidification perspective.

In addition to river alkalinity control in the mid- to low-alkalinity river-influenced estuaries, hydrological conditions also need to be considered in studying estuarine carbonate chemistry. Following the reasoning of ocean and coastal acidification, one may expect that both acidified ocean water (as the ocean endmember) and water column respiration may contribute to acidification of estuaries, as previous simulations have shown (Sunda and Cai 2012; Hu and Cai 2013). However, based on a 40-year data record that is maintained by the Texas Commission on Environmental Quality, a recent study found that the majority of estuaries along the coast of northwestern GOM have been experiencing a gradual loss of alkalinity and a decrease in pH values (Hu et al. 2015). The coastwide estuarine alkalinity decline is attributed to the decline in riverine alkalinity export as many rivers in this region carry high levels of alkalinity although the freshwater resources have been under increasing pressure (diversion for agricultural and industrial usage). Relatively long estuarine residence time (Montagna et al. 2013) may also contribute to further alkalinity consumption due to biogeochemical processes that are not entirely clear (author's unpublished data). On the east coast of GOM, Robbins and Lisle (2017) used a 20 plus-year dataset and found that most estuaries in Florida also have experienced slight acidification. The lower than open ocean pH decrease over time was attributed to local processes such as nutrient-enhanced production. Together, these studies represent two of the very few that examine long-term changes in estuarine carbonate chemistry in general.

Finally, although not located entirely within the GOM, the Florida Reef Tract has been experiencing a latitudinal gradient in net community calcification (NCC). Negative NCC indicates net carbonate dissolution, and positive NCC suggests net carbonate precipitation or calcification. For the Florida Reef Tract, NCC is negative throughout an annual cycle in reefs near the mainland in the north and increases toward the south (Muehllehner et al. 2016). The roles of acidification and direct human influence are not yet clearly understood.

1.3.3.4 Unanswered Questions

Based on the review of previous studies, the following questions are raised about the larger expanse of the GOM.

1.3.3.4.1 Open GOM

Clearly, a knowledge gap exists in the open GOM regarding the rate of acidification: What are the intra-basin differences in the rates of acidification between eastern and western GOM, and in the context of possible reduction in the Loop Current, what would be the long-term trend?

Even though the GOMECC cruises (GOMECC-1, GOMECC-2, and GOMECC-3) provide snapshots of the water column carbonate chemistry from both the coastal region to the open GOM up to 3,000 m water depth, these studies were not specifically designed to examine the open GOM because their focus is to investigate carbon exchange between the shelf and the pelagic ocean. To understand the trend and variability of carbonate chemistry changes throughout the water column, long-term efforts such as setting up time-series stations similar to those in other marginal seas, for example the CARIACO ocean time-series in the Caribbean Sea (Astor et al. 2005) and SouthEast Asian Time Series (SEATS) (Chou et al. 2007), will be needed.

As the only deep water channel that connects the GOM and the Caribbean Sea, which supplies both upper water column and the deep basin waters, the Yucatan Sill (2,040 m) should have a time series station for the examination of both inflowing surface and basin water and subsurface return flow back to the Caribbean Sea (Sturges 2005). In addition, two locations that are in the eastern and western GOM deep basins would also be useful for monitoring long-term changes (Figure 32).

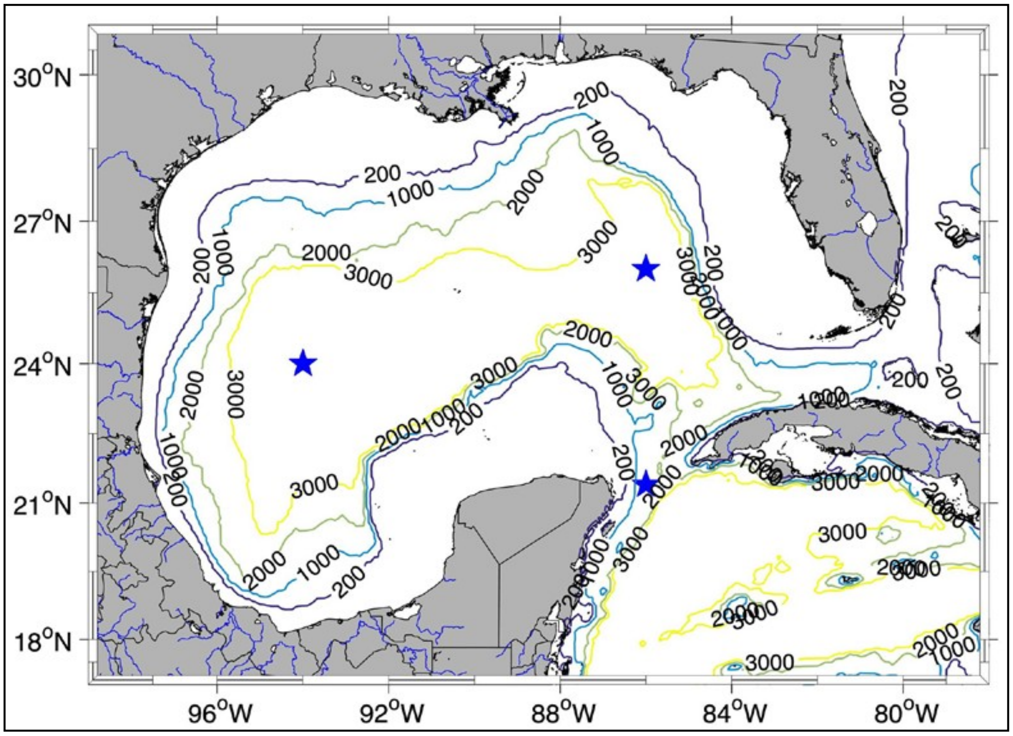

Figure 32. Bathymetry of the Gulf of Mexico.

Blue stars indicate the approximate locations of the proposed time-series stations.

These stations can offer answers to questions not only regarding acidification in GOM, from source water (Caribbean) to the deep basin, but biogeochemical cycle questions associated with climate variability in this important marginal sea. For example, How might the possible future changes in the strength of the Loop Current alter biogeochemical cycles? What are the roles of episodic events (e.g., hurricanes, warm rings originated from the Loop Current) on the biogeochemical processes in the upper water column?

A research topic relevant to OA is the study of anthropogenic CO_2 accumulation in the water column of various ocean basins (Peng et al. 1998; McNeil et al. 2003; Sabine et al. 2004; Sabine and Tanhua 2010; Wanninkhof et al. 2010). Compared to the open ocean, understanding of anthropogenic CO_2 storage in marginal seas is still relatively lacking (Park et al. 2006; Park et al. 2008; Watanabe et al. 2013; Ingrosso et al. 2017). However, the benefit of studying changes in the marginal seas, especially the semi-isolated deep basin, is that the shallow sills around the basin rim can largely “filter” out short-term variabilities in the incoming waters (Joyce et al. 1999) that are often encountered in the open ocean. Therefore, long-term study of deep basins such as the GOM deep waters is beneficial from both the oceanographic and climatic perspectives.

1.3.3.4.2 Acidification in the Southern GOM: Nutrient and Petroleum Impact?

Although perhaps not as serious as in the northern GOM, coastal eutrophication due to nutrients delivered by Mexican rivers has been noted in the literature (Ulloa et al. 2017). As a result, harmful algal blooms have been observed along the Mexican coast of the GOM Large Marine Ecosystem, and the main nutrient sources are Coatzacoalcos River in the southwestern Bay of Campeche and the Grijalva-Usumacinta Rivers in the southwestern Bay of Campeche (Ulloa et al. 2017). It is currently unclear whether coastal eutrophication is associated with any type of acidification effect in this region. Therefore, a question arises: Does eutrophication induce hypoxia in the southwestern GOM shelf, which subsequently leads to coastal bottom water acidification?

The significance of studying coastal OA-related issues is that the southwestern GOM coast hosts a “reef corridor” (Ortiz-Lozano et al. 2013), where reef systems are already severely threatened by anthropogenic activities, including nutrient pollution and sediment loading. Even though the shallow and warm GOM waters are supposed to have relatively high pH and Ω_{arag}, hence acidification alone may not lead to unfavorable conditions. However, in combination with other stressors (low oxygen, high nutrients, and high turbidity), these multistressor effects could be amplified and cause detrimental effects to the calcifiers (DeCarlo et al. 2015).

Finally, given the large oil and gas reserves in the southern GOM shelf region (Tampico-Misantla and Saline-Comacalco basins and the Villahermosa Uplift etc.; Paull et al. 2005), the impact of natural oil and gas release on the water column carbonate chemistry remains an open question. Studying fossil carbon remineralization induced acidification is important given that the rising ocean temperature could both destabilize the uppermost gas hydrate (Lapham et al. 2010; Phrampus and Hornbach 2012) and enhance the rate of microbial respiration (Burdige 2011).

1.3.3.4.3 Estuarine Acidification

Estuaries along the southern GOM coast have a wide range of hydrological conditions, from semiarid Laguna Madre (Mexico side) in the north that is a de facto negative estuary, to intermediate systems such as Laguna Tamiahua and Laguna La Mancha, and then to river-influenced systems including Laguna de Términos. Even though not strictly river-fed estuaries (Moore 1999), along the coast of Yucatan Peninsula, distinct karst systems are present and produce significant coastal subterranean groundwater discharge (SGD; Yáñez-Arancibia et al. 2013). It is probably safe to say that the narrower longitudinal band of the Mexican GOM coast encompasses the same variety of estuarine and coastal systems as exist from Texas to Florida on the US side.

To date, understanding of the Mexican coastal ecosystem and its biogeochemistry is still constrained by the lack of data in general (Camacho-Ibar and Rivera-Monroy 2014), at least in the public domain. Therefore, initiation of environmental monitoring and making available data accessible are essential for the community to begin understanding the “baseline” conditions of these disparate systems. Meanwhile, characterization of carbonate chemistry in the major rivers that feed the various river-dominated estuaries as well as understanding of the metabolic processes (cf. Figure 31) in these riverine estuaries will prove useful for understanding the temporal and spatial variability of carbonate system parameters along the salinity gradient. Information gathered through such research efforts can be utilized by natural resource managers and policy makers in regulating and reducing the human impacts on these environments.

Tidal-driven SGD is shown to affect carbonate chemistry in coral- reef-dominated environments because groundwater typically has much higher CO_2 partial pressure and lower pH than the receiving coastal water due to accumulation of respirational products (Santos et al. 2011; Cyronak et al. 2014; Wang et al. 2014). This type of acidification remains poorly quantified globally. Given that the total SGD could be on par with the total river flux (Moore et al. 2008) and climate variability also controls the SGD dynamics (Gonneea et al. 2013), evaluation of the acidification effect of SGD in the ecologically sensitive coral reef regions is needed. Studies that integrate net community production and net community calcification will be useful to assess the overall health of the corals reefs along the coastline (Andersson and Gledhill 2013).

1.3.3.5 Summary

Compared with that in the open ocean and temperate/subpolar North American coastal regions, OA study in the GOM is still in its early stages with geographical locations currently limited to the northern GOM shelf waters and coastal estuaries in northwestern GOM. There is a knowledge gap in our understanding of how the open GOM responds to atmospheric CO_2 increase, the state of coastal and estuarine carbonate chemistry in the southern GOM, and the acidification effect of SGD along the Yucatan Peninsula.

Understanding these various environments is useful for assessing variability in and limits on living conditions for the numerous calcifying organisms that are both ecologically and economically important. It must be acknowledged that acidification is not isolated from other anthropogenic stressors such as eutrophication/hypoxia and climate-induced changes in nature, including enhanced respiration of marine and seabed-released fossil carbon. Therefore, an integration of expertise from multiple disciplines is needed to investigate OA in the broader expanse of the GOM. International collaborations which focus on the open GOM and assessing the ecological impact of OA on coastal and estuarine organisms will help to push the research forward in this important marginal sea, so that it can better serve the countries around it in a sustainable fashion.

1.3.3.6 Acknowledgements

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1.3.4 Invertebrate Population and Community Studies for Assessing Coastal Gulf of Mexico Environmental Health in the Aftermath of the *Deepwater Horizon* Oil Spill

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1.3.4.1 Abstract

This contribution is intended to add a synthesis of information regarding programs and missions of research programs that generate baseline data that describe existing conditions of invertebrate populations and communities of the coastal GOM. First, we provide a brief history of the findings and outcomes of studies following the DWH oil spill on coastal GOM plants and animals based on selected literature from 2010–2016. Then, we describe research initiatives of the LSU entomology and the UNH genomics programs relative to the initial impact of the spill and recovery of invertebrate populations. Finally, we briefly describe objectives of current research initiatives and goals and objectives for future projects on invertebrate coastal ecology dependent upon future funding and potential international collaborations.

Ultimately, we hope to help create and be active participants in comprehensive sampling programs of the invertebrates found in sediments of different coastal environments of the GOM. The goal would be to create a synthesis of reference databases and multiple-level linked metadata (geochemistry, bioinventories, and genetic information) by sharing samples and cyberinfrastructure among collaborating research groups.

1.3.4.2 Introduction

The purpose of the Gulf of Mexico Workshop on International Research (GOMWIR) was to establish international collaborations among scientists from Mexico, Cuba, and the United States and research priorities for the GOM. There were three thematic areas for open discussion, one of which was regarding recent and current studies that generate baseline data that describe existing conditions for use as future reference. The exchange of information on the research programs of the individual attendees was informal and oriented toward the goal of identifying mutual priorities in the thematic areas. These proceedings, in part, present an opportunity to share information about program missions and opportunities for collaboration.

In this article, we provide a brief history of the findings and outcomes of studies on coastal Gulf of Mexico (CGOM) plants and animals and based on selected literature from 2010 up to and including the proceedings of the GOMRI annual conference held in New Orleans, Louisiana, 6–9 February 2017.

Subsequently, we describe the results of research initiatives of the LSU entomology and the UNH genomics programs relative to: 1) the initial impact of the oil spill and recovery of invertebrate populations, 2) objectives of current research initiatives, and 3) goals and objectives for future projects on invertebrate coastal ecology dependent upon future funding and potential international collaborations.

1.3.4.3 Summary of Selected Literature (2010–2016) on the Effects of the DWH Oil Spill on Plants and Animals of CGOM Habitats

The catastrophic explosion of the DWH drilling platform that occurred on 20 April 2010 caused the largest man-made [sic] marine oil spill to date with a total release of approximately 5 million barrels of oil (Whitehead et al. 2012). The physical spread of the petroleum and other contaminants was measured by large teams of scientists. The visible oil on the surface of the Gulf was tracked using aerial and satellite surveys. The locations and dates of the landfalls were recorded, catalogued, and made available to the public and scientists (ERMA 2017).

Of the 7,058 km of shoreline surveyed using the Shoreline Cleanup Assessment Technique (SCAT), 1,773 km were documented as ever having been oiled. The majority of shorelines with documented oiling occurred in Louisiana (60.6%), followed by Florida (16.1%), Mississippi (14.6%), and Alabama (8.7%). The major shoreline habitats oiled were beaches (50.8%) and marsh (44.9%). Most of the marsh oiling (94.8%) occurred in Louisiana; the beach oiling was distributed across the four states, with 32.9% in Louisiana and 21.1% in Mississippi.

Quantifying the impacts of the spill on the coastal habitats of the GOM that are of ecological and economic importance was and still is critical (Silliman et al. 2012). There have been six years of observations and detailed studies on the primary (acute), secondary (chronic), and tertiary/multitrophic effects of the oiling of pelagic and coastal ecosystems. The primary effects of the explosion of the DHW platform resulted in the loss of 11 human lives, and the subsequent acute oiling in the GOM created visible impact on prominent vertebrates, particularly birds, along the coast (Belanger et al. 2010). More than 7,000 marine mammals, turtles, and birds were found debilitated or dead during the summer months of 2010, and many of these cases were directly attributed to the animals making direct contact with the dispersing oil. For marine vertebrates initially shown to be negatively impacted, reports of recovery for whales (Tang 2017) and deepwater sharks (Gelsleichter 2017) were given at the recent GOM Oil Spill and Ecosystem Science (GOMOSES) meeting, but secondary effects still remain for other vertebrate populations (discussed below).

During and after the spill, massive teams prowled the beaches and barrier island shores cleaning as oiling occurred. The bioavailability of polycyclic hydrocarbons (PAH) was shown to increase at stations at piers along the Louisiana coast after the explosion but returned to pre-oiling levels by March 2011 (Allan et al. 2012). Therefore, there were few studies on the effects of the oiling on organisms in the tidal zones of barrier islands other than acute impacts on vertebrates. However, examination of sediment meiofauna communities (Bik et al. 2002) indicated a dramatic and immediate change in their composition following the DWH oil spill and cleanup effort in 2010, and continued work has shown that "recovered" communities represent distinct assemblages of taxa that differ from known, pre-spill communities (Brannock et al. 2014; Rodríguez et al. 2015).

Because 95% of the oiling of tidal marshes occurred in Louisiana, most studies on the acute oiling effects on estuarine biological communities were and continue to be conducted there, particularly in Barataria Bay. The first reports on acute toxicity were made on the killifish. Subsurface water in Louisiana marshes was shown to have significant concentrations of PAH and acute toxicity to killifish with genomic and physiological changes observed (Whitehead et al. 2012). Further, Whitehead et al. (2012) reported that the PAH concentrations in subsurface water in the marsh locations remained high enough to have biological effects on killifish for up to two months, but they also provided data showing that large amounts of oil were retained in the sediment of oiled marsh at their last sample taken at 5 months after oiling.

The majority of studies on invertebrate populations started with no true pre-event population abundance data, which resulted in having to compare populations in oiled areas compared to areas that were not oiled. Of those studies that showed evidence of population abundance reductions, the majority have reported partial recovery over a 2- to 5-year period. McCall and Pennings (2012) sampled the terrestrial arthropod community and marine invertebrates found in coastal salt marshes. In 2010, intertidal crabs and terrestrial spiders and insects (classified as herbivores, sucking or stem boring parasitoids, and detrivores) were suppressed by oil exposure, but one year later, crab and arthropods had largely recovered. Fleeger et al. (2015) reported recovery of microalgae and meiofauna diversity based upon copepod richness. Our own population census and genetic studies on the horse fly *Tabanus nigrovittatus* showed population crashes in oiled locations compared to unoiled locations in 2010 and 2011 with a slow recovery up to 2016 (Husseneder et al. 2016; Husseneder et al. 2017). By using both population abundance and genetics, we were able to show not only population decline and steady recovery but also how the genetic structure of the population changed immediately after the oil spill and then returned to patterns similar to those in non-oiled control areas.

For primary effects of oiling on plants, Hester et al. (2016) documented significant injury to the plant production and health of Louisiana salt marshes. Marsh sites with vertical oiling of plants had reduction in cover and peak standing crop particularly along the marsh edges for the majority of a 4-year study. Subsequent erosion resulted in plot loss which is consistent with other reports. Lin et al. (2017) found that initial impacts of moderate oiling were evident for *Spartina alterniflora* and *Juncus roemerianus*, but aboveground biomass and total live belowground biomass recovered within 24–30 months. Initial heavy oiling resulted in near complete plant mortality initially, and recovery of total live aboveground biomass was <50% of reference marshes six years after the spill. The *Juncus* vegetation showed no recovery six years after the spill. Furthermore, live belowground biomass of *Spartina* (0–6 cm) in heavily oiled marshes was significantly reduced compared to the reference marshes.

In addition to secondary effects of oiling on plant communities, chronic effects for vertebrates have also been reported. For example, Hicken et al. (2011) showed that sublethal exposure to crude oil causes changes in heart shape and a significant reduction in swimming performance in zebra fish, which likely would result in death in nature. Similarly, Nelson et al. (2016) showed exposure to environmentally relevant PAH concentrations impairs aspects of cardiovascular function, such as cardiac output and stroke work reductions in mahi-mahi. Smith et al. (2017) reported that studies on acute effects of the oiling based on live dolphins and necropsies confirmed lung injury and adrenal gland lesions. Subsequently, reproductive failure rates were evaluated for five years during and after the spill (2010–2015). When compared to the estimated reproductive success rates for dolphins living in areas not impacted by the DWH oil spill, the rates for unaffected areas were three-fold higher than the reproductive success rates for the animals from the affected areas.

Many of the long-term tertiary effects of the oiling will go unnoticed or undescribed due to lack of direct links. However, there have been observable and permanent tertiary effects of oiling shown for *Spartina* marsh land loss associated with the primary acute impact on the vegetation, the secondary significant impact on belowground vegetation, and ultimately the tertiary loss of the heavily oiled banks associated with the oiling and subsequent wave action of tropical storms (Rangoonwala et al. 2016). The authors measured the relative impact of wetland loss in Barataria Bay, Louisiana over a period of 1 year before the oiling to 2.5 years after oiling using synthetic aperture radar. They showed that there were significant differences in the loss of land before and after oiling (which was not observed in control areas).

Specifically, land loss was greater in 2012 due to wave-induced erosion associated with Hurricane Isaac. Factors affecting this phenomenon include decreases in belowground biomass (Lin et al. 2002) and weakened soil (McClenachan et al. 2013) in salt marshes. McClenachan et al. (2013) described shoreline studies showing that soil weakened by oiling resulted in more erosion than was obvious from aboveground observations. This resulted in an overhang of even moderately oiled marsh banks with collapse of the overhang when it became too large.

1.3.4.4 Research Initiatives of the LSU Entomology and UNH Genomics Programs

1.3.4.4.1 Relevant Previous Research, LSU

From immediately after the spill in April 2010 until November 2011, we conducted studies on greenhead horse fly (*Tabanus nigrovittatus*, Figure 33) populations at four Louisiana locations west of the Mississippi River. Two locations were oiled (Grand Bayou and Grand Isle) and two were not (Cypremort Point and Cameron). Horse flies are members of the family Tabanidae, which has over 4,000 species. Insect population surveys are often used as biological barometers of the health of freshwater ecosystems. However, studies on insect biology in brackish and saline ecosystems are relatively few because there are few insect species that are osmotolerant. The greenhead horse fly is one of the few species of tabanids that are found in these extreme environments.

Figure 33. Larva and female adult of the greenhead horse fly, *Tabanus nigrovittatus.*

Photos by C. Hussender.

The rationale for selecting the greenhead horse fly as the entomological model for coastal ecology studies is that this species is native to and tightly bound to specific coastal marsh habitats that range from the Texas coast to Nova Scotia. Therefore, this insect species can be useful as a bioindicator for ecologists along both the Gulf and East Coasts. Furthermore, there are closely related species that are native to tidal marshes in many other parts of the world. The adult female flies are highly mobile, easy to catch and identify, and are highly apparent to local human populations because of their pestiferous attacks. The seasonality of the adult populations is relatively well established in most of the species' range and the life cycle is well described. Female greenhead horse flies are autogenous, which means that the first batch of approximately 150 eggs is produced before the fly pursues its first bloodmeal. This attribute results in the property of the annual populations being independent of available vertebrate hosts. There are few autogenous tabanid species and the majority of these species are found in extreme environments such as brackish marshes and subarctic zones.

We compared the population abundance and genetic structure of the adult horse flies between the unaffected and oiled locations. Adult flies were collected biweekly from June 2010 until October 2011 using at least four canopy traps per location. We also collected horse fly larvae in 2011. Horse fly abundance estimates showed severe crashes of adult tabanid populations as well as reduced numbers of larvae recovered from the soil in oiled areas (Husseneder et al. 2016). Our trap data with only a range of 1.3–4.8 mean flies captured per hour in 41 trap days indicated that the adult tabanids had been affected immediately after the oil spill reached Elmer's Isle, Grand Isle (Jefferson Parrish) and Grand Bayou (Plaquemines Parish); both of these areas had been notorious for greenhead attack each summer. In comparison, fly activity remained high at the unaffected locations at Cypremort Point (St. Mary Parish) and Cameron Parish (a range of 36.6–92.2 flies per hour in 60 trap days).

At each of the four regions the mean number of flies per hour trapped was not significantly different between the years 2010 and 2011 (Table 2). In 2010, horse fly numbers differed significantly (P = 0.0042) between all four regions, while in 2011 catches at the two unaffected locations (Cameron, St. Mary) were equally high and catches at oiled locations (Jefferson, Plaquemines) were equally low. Overall, in both years, horse fly numbers caught at unaffected locations were significantly higher (P < 0.0001) than at oiled locations (Table 2). As expected, the number of trapped flies fluctuated seasonally at each location but counts at oiled locations were in most cases orders of magnitude lower than those at unaffected locations.

Table 2. Mean number of greenhead horse flies trapped (flies/hour) by region in 2010 and 2011

(Husseneder et al. 2016) Letters a, b, c, d indicate statistical differences in the mean number of horse flies trapped at each site by year; counts with the same letter are not statistically different (P < 0.05; Tukey-Kramer).

Parish	2010			2011		
	Mean ± SE	Mean (log x+1) ± SE		Mean ± SE	Mean (log x+1) ± SE	
Cameron	82.2 ± 6.6	3.9 ±0.2	a	53.2 ±6.9	3.3 ± 0.2	ab
St. Mary	38.0 ± 6.6	2.6 ±0.2	b	38.0 ± 6.5	3.3 ± 0.2	ab
Jefferson	0.8 ± 6.1	0.4 ± 0.2	d	1.3 ± 6.5	0.6 ± 0.2	d
Plaquemines	3.9 ± 5.8	1.2 ± 0.1	c	4.5 ± 5.4	1.1 ± 0.1	c

In support of the observed impact of oil intrusion on adult horse flies, we recorded lower incidence rates of larva recovery from oiled areas. At Grand Isle, no larvae were collected from any of the six collection sites; at Grand Bayou, one tabanid larva was isolated from only one of eight sediment samples. In contrast to oiled areas, there was a high probability of collecting tabanid larvae in those *Spartina* marshes in Louisiana that were not affected by the oil spill. Tabanid larvae were isolated from four of the five samples obtained in Cameron; the maximum number of larvae was 10 with an average of 3 per sample. From Cypremort Point, larvae were isolated from five of the eight samples; the greatest number of larvae was 2 with an average of 1.

Microsatellite genotyping of six non-oiled and seven oiled populations at ten polymorphic loci detected genetic bottlenecks in six of the oiled populations in association with fewer breeding parents, reduced effective population size, lower number of family clusters, and fewer migrants among populations (Table 3). This data was published by Husseneder et al. (2016) and is the first study assessing the impact of oil contamination at the level of a top arthropod predator of the invertebrate community in salt marshes.

Table 3. Summary of the differences between populations of tabanids from oiled and non-oiled areas

(Husseneder et al. 2016)

Parameter	Non-oiled	Oiled
Adult fly counts	High	Low
Larvae recovered from marsh soil	High	Low
Effective population size	High	Low
Number of breeders	High	Low
Number of families	High	Low
Number of migrants, gene flow	High	Low
Genetic bottlenecks	No	Yes

Whether a population originated from non-oiled or oiled areas had marginally significant effects on genetic distance and significant effects on the number of migrants per generation (General Linear Model [GLM]: F = 4.06, df = 1, P = 0.069 and F = 19.13, df = 1, P = 0.001, respectively). Although non-oiled populations were separated by larger geographic distance (40–105 km) than oiled populations (6–45 km), the genetic distances among them were on average marginally smaller (mean F_{ST} = 0.17, SE = 0.02) and thus gene flow was higher than among oiled populations (mean F_{ST} = 0.22, SE = 0.01, P = 0.090, 2-

tailed t-test, SPSS). This indicates that the observed population crashes in oiled areas might have resulted in a fragmentation and reduced migration/survival of immigrants. Oiling of the area also caused significantly lower numbers of parents contributing offspring to the population (P = 0.048, df = 1, F = 5.21), lowereffective population size (P = 0.03, df = 1, F = 6.75), and lower number of offspring per parent (P = 0.076, df = 1, F = 4.02). Oiling had a marginal effect on the number of family clusters being lower in oiled areas (P = 0.095, df = 1, F = 3.48).

No bottleneck effects were detected in the six populations from non-oiled areas in 2010 or 2011 under any of the three mutation models tested (IAM, TPM, SMM as implemented in BOTTLENECK v.1.2.02, Piry et al. 1999). However, five out of seven populations that were hit by the oil spill showed pronounced genetic bottlenecks in 2010 and/or 2011, and an additional population showed a marginal bottleneck effect. These results reflect the observed population crashes and further emphasize the devastating impact of oiling on the top predator of the invertebrate marsh community. The populations with marginal or no bottleneck were those collected on Grand Isle that also showed genetic heterogeneity and the presence of a genetic cluster predominantly known from unaffected locations. This might be a sign of beginning recovery via immigration (Husseneder et al. 2016).

In 2016, we repeated the procedures used to compare the population abundance and genetic structure of the adult horse flies between the unaffected and oiled locations in 2010 and 2011. We found that in 2016 adult fly counts had increased in oiled areas and we were able to retrieve larvae from marsh soil in oiled locations previously devoid of larvae. Moreover, the population genetic structure showed signs of recovery. The genetic bottlenecks in populations from previously oiled areas have largely disappeared. Effective population size and the number of breeders, families and migrants have reached the levels of non-oiled populations (Husseneder et al. 2017). These studies showed the value of population genetic data for signs of impact and recovery in connection to census data or as a stand-alone method for species that are not accessible to reliable, time and cost intensive long-term population census regimes.

1.3.4.4.2 Description of Current LSU Studies

We currently are continuing to monitor the population abundance of adult tabanids in our previous study locations, and specimens are stored for future genetic analysis if required. We also have expanded our larval tabanid surveys to establish seasonality and distribution of the larval life stages and their prey. We are testing the hypothesis that the presence of the apex predator tabanid larva represents a healthy and likely diverse food chain within the marsh sediments. We are using metagenetic analyses to compare the micro- and meiofauna community in the immediate environment where tabanid larvae are found as well as the community in spartina marsh sites devoid of tabanid larvae. We also have initiated studies to analyze the gut content of tabanid larvae to identify prey species and compare their composition to that in the surrounding marsh soil. Based on this knowledge we will develop a time- and cost-efficient PCR-based diagnostic method to differentiate between healthy and biologically depleted marsh soil.

Relative to the tabanid larval food web, we have obtained 18S rRNA gene sequences (Illumina MiSeq, 2 X 300bp) of 2011 soil samples from oiled and non-oiled areas and gut contents of greenhead horse fly larva to describe the larval food web, taxa diversity across sample types, and begin the search for bioindicators of marsh health. The most abundant families are the same in the sediments and guts from oiled and non-oiled locations, although the relative abundance varies across sample type. Differences in the meiofauna composition at oiled and non-oiled locations might be due to differences in geographical location, soil chemistry, or oil tolerance. We found that hexapods and fungi are among the most abundant families across all our sample types. These taxa are also important staples in the diet of tabanid larvae.

We also have expanded our insect surveys of the coastal marshes to include other species that are native to these habitats, with “native” here defined as those species that complete their entire life cycle within these brackish marshes. These surveys include both adult and larval stages. Because there are few useful taxonomic keys for use in identification of insect larvae (including tabanids) from these marshes, we will use DNA barcoding to aid in the identification of the life stages of the different native species. Obviously, insect larvae are staples of the tabanid larval diet resulting in overlap of these new initiatives.

1.3.4.4.3 Relevant Previous Research at UNH

The Thomas laboratory has a long history of developing molecular methods of taxonomy and biodiversity assessment including the initial development of PCR-based methods of population genetic analysis now widely adopted in metabarcoding (Kocher et al. 1989). More recently, the Hubbard Center for Genome Studies (HCGS) at UNH was among the first to apply next generation sequencing technologies to the analysis of organismal evolution and has worked with many diverse international groups toward development of novel approaches to monitor community structure with a particular emphasis on meiofauna, specifically nematodes that are among the most abundant and diverse sediment and soil animals (Bik et al. 2012; Creer et al. 2016). That emphasis included the development of novel bioinformatics tools for the analysis of next generation metabarcoding and metagenomics datasets (Gaspar et al. 2013, 2015; Westbrook et al. 2017). UNH is also home to an NSF-funded Research Coordination Network "EukHiTS" (DBI-1262470) focused on integrating research activities investigating the application of high throughput sequencing for analysis of eukaryotic biodiversity. As part of this Research Coordination Network and the NH-INBRE, Thomas and colleagues are developing a series of bioinformatics workshops with online modules suitable for research training and for implementation in course curricula. With regard to the GOM and the consequences of the DWH event, the HCGS at UNH first applied metabarcoding approaches to assay the consequences of oil contamination on benthic microbial eukaryotes (Bik et al. 2012). In addition to the observed dramatic shifts in meiofaunal community structure observed, it became obvious that the lack of robust reference datasets for the vast majority of meiofaunal species was a major impediment to developing a mechanistic understanding of biological diversity for these creatures necessary to support logical approaches to mitigation and remediation. Ultimately, those observations led to the current focus of the UNH research group.

1.3.4.4.4 Description of Current UNH Studies

To date, draft genomes have been generated for 39 species that represent 11 phyla, six with no previous genome wide sequence data. In addition, we have established new approaches for the analysis of shotgun metagenomics datasets allowing for the elucidation of population level analysis. The draft genomes revealed the standard rRNA loci and large numbers of complete single copy orthologs. These genomes will serve as references for shotgun metagenomics analysis including taxonomic characterization of communities, and description of metabolic pathways. These references support expanded metabarcoding applications by providing the sequences necessary for primer design for large numbers of universal orthologs as well as population genetic markers (e.g., microsatellite loci) for analyses of intraspecific variation and population genetic structure. Intraspecific variation also addresses some of the major shortcomings of metabarcoding namely the existence of cryptic ecologically unique species and a lack of species-level resolution afforded by standard barcoding approaches using rRNA gene sequencing.

As part of our commitment to development of resources for investigating GOM meiofaunal diversity, we established a workshop on "Benthic Invertebrate Taxonomy, Metagenomics and Bioinformatics" (BITMaB) at HRI. That workshop brought together an international group of taxonomic experts and bioinformatics specialists, as well as students, to collect and identify the specimens for the reference genomes as well as learn about the diversity of microbial eukaryotes and the training in bioinformatics skills to conduct the analysis. The 2017 workshop was cosponsored and supported by GOMRI and NSF and included 59 scientists from around the world. The participants represented all levels from undergraduate students to professors, staff scientists, and personnel from regulatory agencies.

1.3.4.4.5 Description of Future LSU and UNH Studies

We have provided a synopsis of studies that describe the acute effects of the primary oiling events and both expected and unexpected secondary and tertiary effects associated with the DWH oil spill. What effects these changes have on current and future biological communities of the CGOM is an important question for the GOM scientific community. The primary issue that hindered scientists from assessing the acute effects of the 2010 oiling of different coastal habitats was the absence of pre-event, baseline data. The DWH oil spill should serve as a wakeup call for funding agencies regarding the paucity of baseline information available for the CGOM biological communities. In the future, there is always the potential for new deepwater oil exploration disasters to go along with the slow, steady decline in coastal GOM estuary health associated with climate change, sea-level rise, subsidence, and other man-made disasters; having baseline ecological data accessible to future scientists is a mandate. In this section, we present some potential goals and objectives for future projects on invertebrate coastal ecology that we hope to achieve, depending on future funding and the potential for international collaborations.

For future projects, a major goal would be to identify composition, density, and variation of meiofaunal communities across healthy intertidal zones and those impacted by the DWH oil spill as well as other geographic locations to establish baselines for changes in response to ecological conditions using quantitative PCR, DNA barcoding, metagenomics, and population genetic approaches. Projects to conduct morphological and genetic identification of macrofauna native to marshes and barrier islands also would be key elements.

We have previously used 18S metabarcoding to show effects of the DWH oil spill on a limited number of meiofaunal communities (Bik et al. 2012). A major focus of future studies would be to expand these applications for studies of the invertebrate communities of different coastal habitats of the entire GOM to provide baseline data for future monitoring activities. While the relative gain and loss of taxa from complex specious communities can provide valuable information about the consequences of environmental change, we also expect profound consequences on genetic diversity and patterns of migration, among other parameters of population structure that can be measured while not being detected at the level of species diversity (Husseneder et al. 2016).

Through the development of reference genomes, we predict that it will be possible to extend analysis of largely unstudied/understudied meiofaunal species to the population level. As shown above these reference genomes include new information to support the goal of extending metagenomics analysis to the level of population structure. Specifically, each new meiofaunal reference genome includes vast numbers of single nucleotide polymorphisms (SNPs), microsatellites and complete mitochondrial genomes. This genomic sequence data makes it possible to perform targeted assays of population structure for hundreds of invertebrate species of the GOM. For each species the reference genome allows for the selection of nuclear loci that are known to be polymorphic (such as microsatellites) and to design primers that are unique to the targeted locus. Further, the mitochondrial genomes of animals (including these meiofauna) evolve rapidly and without recombination and have served as an excellent locus for the establishment of phylogeographic structure.

In the future, we intend to use two strategies to assess intraspecific variation. One strategy would be based on traditional analysis of individual specimens using mtDNA haplotypes and microsatellite genotyping by sequencing approaches. A second strategy will be to test and validate the utility of whole metagenome shotgun data to allow parallel population genetic analysis of many species simultaneously. The individual-based approach allows the use of classical heterozygosity-based population genetic statistics (Husseneder et al. 2016), but is strongly biased towards large, abundant species that are easy to collect and identify. The novel approach of shotgun metagenomic analysis of a large number of alleles and their frequencies can provide population level assays in parallel of a community of species, including abundant, but small and less described organisms.

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1.3.5 Biophysical Interactions Driving Tuna Larvae Presence in Cuban Waters in the Gulf of Mexico: Recent Efforts by NOAA/SEFSC, NOAA/AOML and UM/RSMAS/CIMAS

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1.3.5.1 Abstract

Bluefin tuna and other tuna species are crucial economic and ecological resources of the northern Atlantic. Although the GOM is a known spawning ground for bluefin tuna, little is known about bluefin spawning activity in the southern Gulf, especially in Cuban waters, and there is little information concerning spawning activity of other tuna species such as yellowfin and skipjack tuna. The specific ocean circulation of the Gulf, dominated by the Loop Current, is expected to play a role in the distribution of tuna larvae in the region, but the extent of these biophysical interactions is not precisely known. Two cruises were led by NOAA in spring 2015 and spring 2016, in collaboration with scientists from Mexico and Cuba, to elucidate the patterns of Atlantic bluefin tuna spawning, and their connection to local circulation. Scientists at the University of Miami provided real-time model simulations of ocean circulation, which were useful for analyzing features of interest that might influence local and regional biophysical connectivity.

1.3.5.2 Introduction

Atlantic bluefin tuna (*Thunnus thynnus*) spawn in late April to early June in the GOM at temperatures above 23 °C (Richards 1976). Spawning activity is primarily focused in the north-central GOM. However, bluefin tuna larvae have also been reported from the Straits of Florida (Richards and Potthoff 1980; Brothers et al. 1983; Figure 34), southwest GOM (Olvera Limas et al. 1988), and along the East Coast of the United States as far north as the Carolinas (McGowan and Richards 1989). Recent work has suggested that bluefin may also spawn off the Yucatan coast of Mexico, as well as north of the Bahamas (Muhling et al. 2011; Lamkin et al. 2014). The extent and frequency of spawning in these outlying habitats is unknown. Blackfin (*T. atlanticus*), yellowfin (*T. albacares*), and skipjack (*Katsuwonus pelamis*) tuna also spawn in the GOM and western Caribbean and, though not as economically important as bluefin, they play a critical ecological role both as food fish and as top predators. Samples collected as part of NOAA's Southeast Area Monitoring and Assessment Program (SEAMAP) suggest blackfin tuna are ubiquitous in the ichthyofauna of the northwestern GOM. Less is known about yellowfin and skipjack tuna, which are observed frequently but are not as widely distributed. Outside of the area surveyed in the nothwestern GOM, little is known about the ecology and distribution of these species in the southern GOM. Of particular interest is the potential spawning activity of bluefin tuna north and south of Cuba.

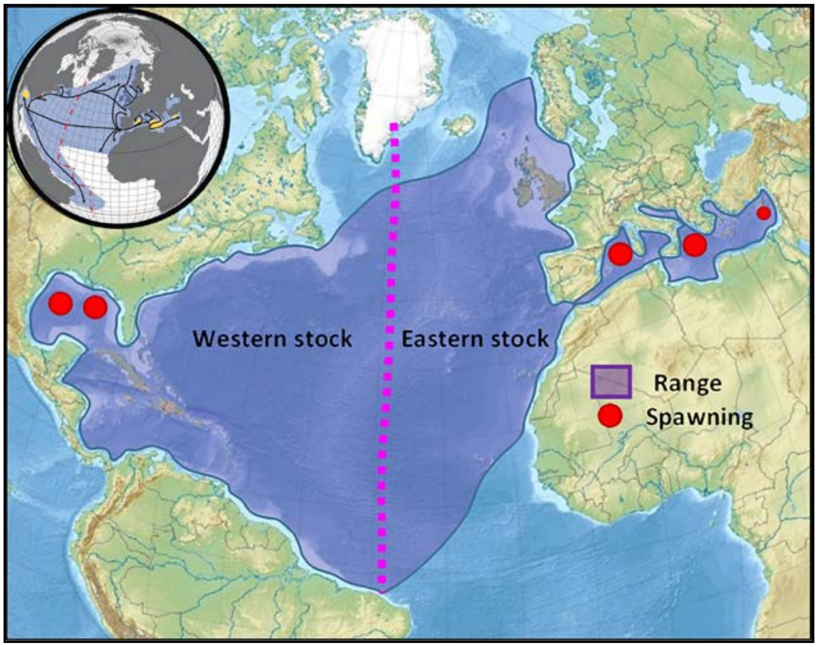

Figure 34. Atlantic bluefin tuna migrate from the North Atlantic to spawn in the summer.

Adult bluefin tuna are distributed throughout the North Atlantic and are exploited with a variety of fishing gears throughout their range. The western Atlantic bluefin stock is estimated to have declined precipitously during the 1970s and early 1980s, but it has been relatively stable since the implementation of quotas in 1982. The NOAA Southeast Fisheries Science Center (SEFSC) has developed a fishery independent index for the western bluefin stock using larval bluefin tuna abundances from annual ichthyoplankton surveys. These surveys have been carried out since the late 1970s, and since 1982 have been completed as part of the SEAMAP program (Scott et al. 1993, Ingram et al. 2010). The larval index is an important component of the bluefin stock assessment, as well as the development of habitat models to improve the index (Lamkin et al. 2015). However, an effective index should account for significant spawning outside the survey area, so it is important to determine the extent of spawning habitat in adjacent oceanographic areas, such as Cuba.

The NOAA National Marine Fisheries Service (NMFS) has a long but infrequent history of biological sampling near Cuba dating back to the Deep Sea Research expedition in 1919. The oceanographic and fisheries vessel *Albatross* conducted sampling at a series of plankton stations from the Florida Keys to Havana, and across the Yucatan Channel; the samples are archived in the Smithsonian Museum of Natural History. However, these sampling efforts were sporadic and there has not been a systematic effort to sample for bluefin and other tuna larvae by the United States. Other efforts were historically made to sample for adult tuna south of Cuba, such as Bullis and Mather's (1956) collection of adult bluefin tuna in April 1955. These surveys were not repeated, and the extent of bluefin habitat in the western Caribbean and the Florida Straits is unclear.

Interest in larval bluefin spawning habitat around Cuba had been growing as the SEFSC and the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) further refined the larval index and sought to understand the extent of spawning outside the GOM. Little is known about the ichthyoplankton in the region, or the mesoscale physical oceanographic features that drive productivity (see Figure 35). Understanding the biological-physical connection and drivers of recruitment is a priority to the SEFSC and key to understanding bluefin larval dynamics. As a result of these interests, NOAA (SEFSC, AOML) proposed conducting larval/physical oceanography surveys around Cuba and developed a collaboration with scientists from Mexico (ECOSUR) for sampling physical parameters and analyzing ocean circulation patterns. In 2014, Cuba agreed to allow sampling within their waters and participated in NOAA-led cruises in 2015 and 2016. These surveys sampled the waters around Cuba and the Yucatan extensively in 2015 and concentrated on northern Cuba in 2016 (Figure 36). Mexico and the United States signed a Memorandum of Understanding (MOU) for MPA conservation and management in 2012, which favors the establishment of a sister sanctuary relationship in the region. More recently, the United States and Cuba established relationships between Guanahacabibes National Park and Banco de San Antonio in Cuba, and the Florida Keys National Marine Sanctuary and the Flower Garden Banks National Marine Sanctuary in the United States under the MOU signed in November 2015. All of these MPAs are connected by the regional ocean circulation.

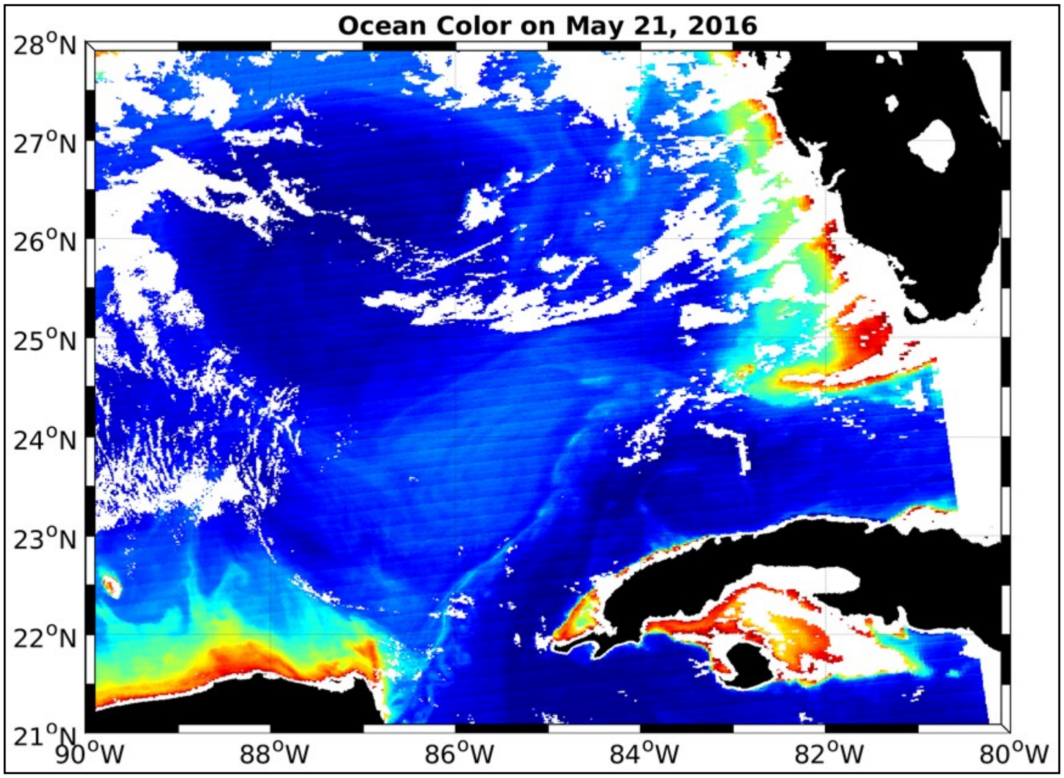

Figure 35. Chlorophyll-*a* (Chl-*a*) in the Southeastern GOM on May 21, 2016, during the NOAA cruise around Cuba.

Chl-*a* map is from Modis Aqua, and color shading indicates relative Chl-*a* values from low (blue) to high (red). Source: University of Southern Florida College of Marine Science Optical Oceanography Lab.

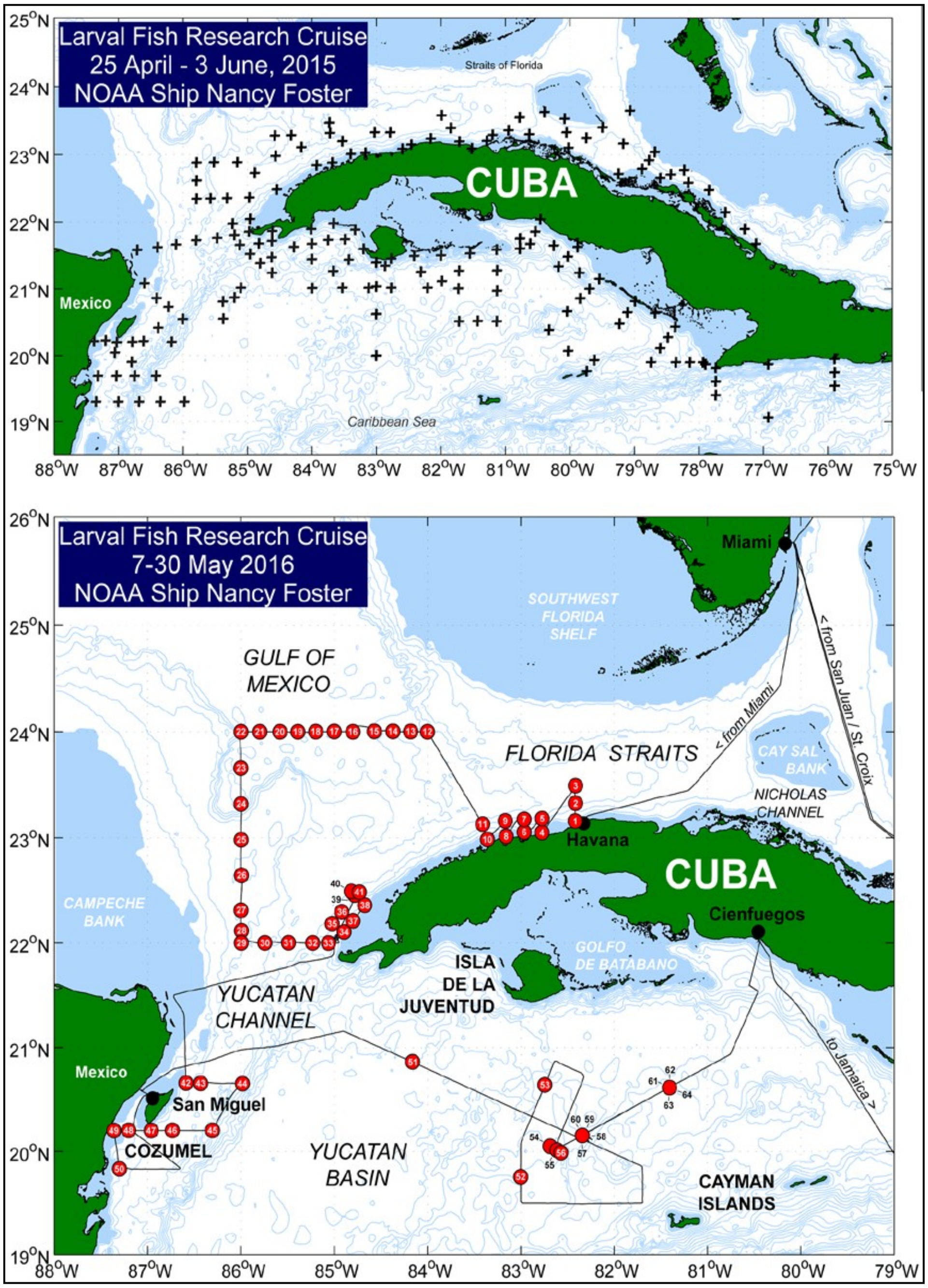

Figure 36. 2015 cruise sample locations (upper); 2016 cruise sample locations and survey tracks (lower).

Collaboration with oceanographers at the University of Miami and NOAA/AOML supported the analysis of oceanic circulation that drives the connectivity among GOM coastal and deep ecosystems. The dominant circulation feature that affects the Cuban waters within the GOM is the Loop Current (LC), which is the local portion of the North Atlantic western boundary current. The LC enters the GOM via the

Yucatan Channel between Mexico and Cuba, and exits at the Straits of Florida, between Cuba and Florida, where it becomes the Florida Current, and finally the Gulf Stream along the southeastern United States. The pathway of the LC within the GOM varies in time, from a retracted, or port-to-port position, to an extended position. In its retracted position, the LC flows almost directly from the Yucatan Channel to the Straits of Florida, and through most of the northwestern Cuban waters. In its extended position, the LC flows northward and reaches the edge of the northern GOM continental shelf near the Mississippi Delta, before turning clockwise and southward toward the Florida Straits. When extended, the LC eventually closes its clockwise circulation, resulting in the formation of a large, warm-core eddy that then drifts westward inside the GOM, before dissipating when interacting with the western GOM shelf and coasts. After shedding a warm-core eddy, the LC typically retracts to the port-to-port position. The eddy shedding frequency is highly variable, 2–19 months, with most frequent occurrences at 6, 9, and 11.5 months (Leben 2005). The eddy shedding sequence often involves temporary detachments and re-attachments of the warm-core eddy, before final separation (Schmitz 2005). Small, cold-core eddies with anticlockwise rotation form and propagate at the outer edge of the LC and play a role in the detachments and separations of LC warm-core eddies (Fratantoni et al. 1998; Chérubin et al. 2005, 2006; Le Hénaff et al. 2012, 2014; Athié et al. 2012). These cold-core eddies also affect the meandering of the Florida Current in the Straits of Florida, so that when one of these eddies is present on the northern side of the current, the current is deflected toward Cuba (Fratantoni et al. 1998; Kourafalou and Kang 2012). As a result, all of the LC stages affect the ocean circulation over northwestern Cuban waters.

Understanding the relationship between the abundance and distribution of bluefin tuna larvae and the ocean circulation is even more difficult in the Cuban waters of the GOM, as aside from the general LC circulation, smaller scale circulation features are poorly understood in this area. Indeed, due to the geopolitical situation regarding Cuba in the past decades, there have been almost no in situ physical oceanography data collected in Cuban waters which are publicly available to the international scientific community to study the local circulation. An exception occurred with the collaboration between Cuba and Mexico to measure the transport associated with the incoming LC in the Yucatan Channel, which allowed a countercurrent toward the Caribbean Sea along the Cuban coasts to be identified (Ochoa et al. 2001). However, the circulation along the Cuban coasts north of the Yucatan Channel is still poorly known. In addition, despite the availability of satellite data and the possibility of using numerical models in that region, there are very few studies that focus on, or even mention specific circulation patterns around Cuba. A recent study by Kourafalou et al. (2017), based on remote sensing and numerical modeling, identified clockwise circulation eddies, named Cuban Anticyclones (CubANs), that form at the base of the LC close to the Cuban coasts and propagate eastward in the Straits of Florida, affecting the meandering of the LC and the Florida Current. These CubAN eddies tend to form when the LC is retracted and are sometimes found together with cold-core filaments or eddies associated with coastal upwelling (Kourafalou et al. 2017).

Thus, the objectives of the 2015 and 2016 research surveys that focused on the GOM bluefin tuna ecosystems were to: a) characterize the presence of bluefin tuna larvae in Cuban waters, b) characterize the ocean circulation processes in these waters, and c) improve our understanding of the interactions between the ocean circulation and the biology affecting bluefin tuna. Preliminary data from 2015 are presented here; samples from 2016 have been sorted, but not yet identified. In addition, the authors would like to note that these surveys are only a snapshot of the biological and physical processes in an ecologically complex region. A longer-term collaborative research effort is needed to develop an understanding of the regional complexities and the biological connections linking the western Caribbean and the GOM, including the Florida Straits. How the data used for the study were collected is presented in the next section, followed by sections detailing the preliminary results related to the cruises objectives, and providing conclusions and recommendations for future research related to this topic.

1.3.5.3 Data Collection

The survey work associated with both the 2015 and 2016 cruises included shipboard zooplankton samples collected with a 1 m × 2 m 505 µm mesh plankton net towed from the surface to 50 m, and additional tows that just sampled the upper 10 m. Zooplankton was also collected with a mini bongo with a 200 µm and 30 µm mesh net, as well as a Multiple Opening and Closing Net Environmental Sensing System (MOCNESS). Conductivity-Temperature-Depth (CTD) casts measuring temperature, salinity, dissolved oxygen, chlorophyll, colored dissolved organic matter (CDOM), and water velocity were collected at each station. Continuous surface measurements of temperature, salinity, chlorophyll, CDOM, and water velocity were also collected via the ship's flow-through system and hull-mounted 150 kHz Acoustic Doppler Current Profiler (ADCP). Satellite-tracked, Lagrangian surface drifters were also deployed to study the regional circulation. Satellite imagery of sea surface temperature, altimetry, and ocean color data are used to aid in the interpretation of shipboard data and drifter observations.

In addition to these observational data, we have access, through the Ocean Modeling and OSSE Center (OMOC) between NOAA-AOML and the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami, to two model simulations in order to analyze some of the circulation patterns observed in Cuban waters. These simulations are based on the HYbrid Coordinate Ocean Model (HYCOM). The first simulation covers the full GOM at 1/50° (~2 km) resolution and has data assimilation capabilities (Le Hénaff and Kourafalou 2016). The second simulation (FKEYS) is centered over the Straits of Florida, with a higher resolution of 1/100° (~900 m) and is nested in the operational Navy GOM simulation (Kourafalou and Kang 2012). The FKEYS simulation has been used to study CubAN eddies (Kourafalou et al. 2017). Both model configurations are currently run in near real time.

1.3.5.4 Results

1.3.5.4.1 Physical Processes

In 2015, the cruise sampled the GOM Cuban waters at a time of extended LC during late May–early June. The cruise sampled the Yucatan Channel, then the GOM Cuban waters from West to East (Figure 36, upper panel). The onboard ADCP data show the intense anticyclonic circulation associated with the LC northwest of Cuba, as the direction of the current shows a marked clockwise circulation. The LC is also clearly visible in satellite altimetry, as it is associated with an elevated sea surface height (SSH). In the Florida Straits, the ADCP data record the intense flow of the Florida Current very close to the Cuban coasts, associated with a meandering of the current clearly seen in the altimetry. Such meandering of the Florida Current, usually associated with the presence of cyclonic eddies north of the current (Fratantoni et al. 1998; Kourafalou and Kang 2012), strongly affects the local circulation in Cuban waters. Examination of ocean color data on 21 May 2015 (Figure 37, upper panel) shows the presence of a filament of elevated surface chlorophyll-*a* (Chl-*a*), a portion of which seems to originate from the western tip of Cuba, just offshore the Gulf of Guanahacabibes. This filament is entrained along the LC toward the northwest and the GOM interior. The onboard ADCP data show a short cyclonic veering of the current just south of the LC associated with the filament. The orientation of the coast at that location and the dominant winds are favorable for upwelling, which is usually associated with cyclonic activity (Kourafalou et al., 2017). This is consistent with the ADCP observations.

In 2016, the GOM section of the cruise started from Havana and sampled Cuban waters to the west, toward Mexico (Figure 36, lower panel). At that time, the LC had just shed a large, warm-core anticyclonic eddy. The 2016 cruise was able to sample the very large LC frontal cyclonic eddy that took part in the LC warm-core eddy separation. The ADCP sampled the cyclonic circulation patterns (Figure 37, lower panel). Ocean color imagery shows elevated Chl-*a* levels within this cyclonic eddy, compared to surrounding areas. Drifters were deployed at the core of the eddy. The shedding of the LC warm-core eddy was associated with the retraction of the LC to its southern position, which makes the 2016 conditions very different from the 2015 cruise.

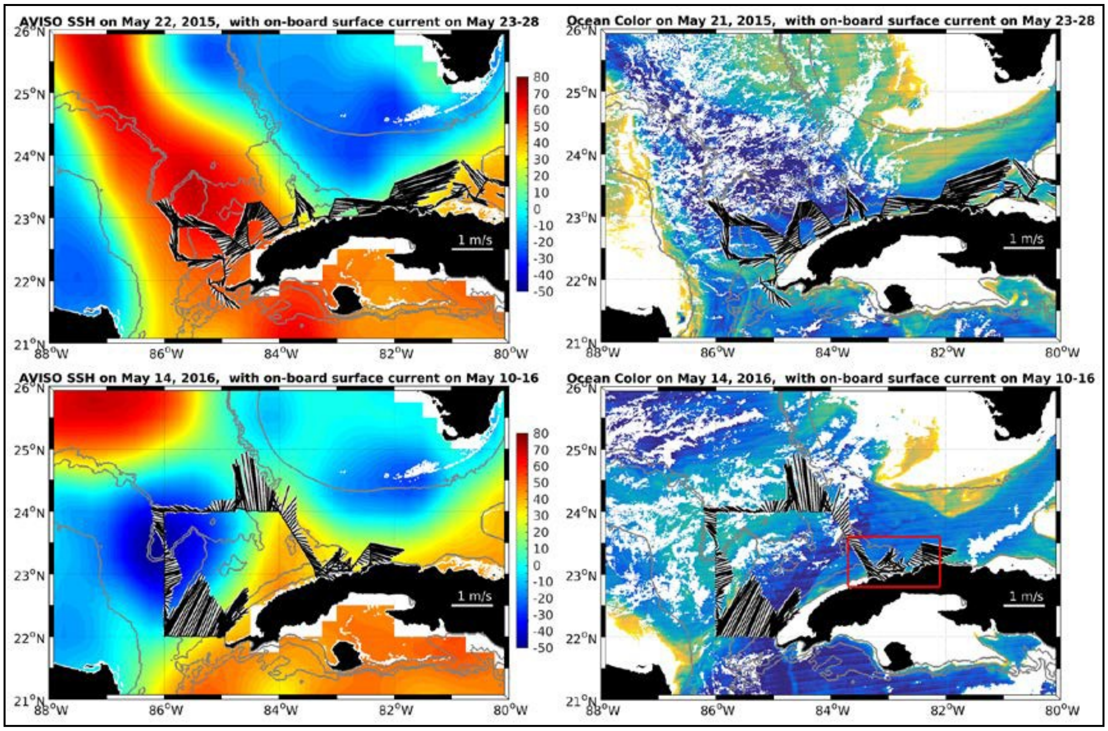

Figure 37. SSH and Chl-*a* concentrations for May 2015 (top) and May 2016 (bottom).

SSH (cm) is from AVISO altimetry observations on 22 May 2015 (top) and 15 May 2016 (bottom) with surface ADCP current vectors on 21 May 2015 (top) and 14 May 2016 (bottom). Figures include surface current vectors (black and grey lines), selected isobaths (light grey lines at 200 m, 2,000 m, and 3,000 m), and the area for the zoom on Figure 38. Chl-*a* maps (right) are from Modis Aqua, and color shading indicates relative Chl-*a* values from low (blue) to high (orange). Source: University of Southern Florida College of Marine Science Optical Oceanography Lab.

The cruise also sampled small-scale processes along the coast of Cuba. Just west of Havana, the survey cruise sampled a filament of high Chl-*a* waters also evident in the concurrent remotely sensed data (Figure 38, upper panel). The onboard ADCP indicates a localized offshore current, surrounded by anticyclonic current veering east of the filament, and a cyclonic current veering west of it, where the high Chl-*a* was observed. The cyclonic circulation pattern and the presence of high Chl-*a* waters are typical of coastal upwelling. The anticyclonic circulation pattern is consistent with the formation of anticyclonic eddies along the northern coasts of Cuba (Kourafalou et al. 2017). Figure 38 (lower panel) shows the presence of a similar pattern in the near-real-time GOM-HYCOM 1/50° simulation during the same period. The simulated sea surface temperature (SST) is lower west of the jet, consistent with the presence of upwelling. The simulated currents show similar patterns of anticyclonic and cyclonic circulation patterns forming an offshore jet, as observed during the 2016 cruise. Similar circulation patterns are also seen in the FKEYS-HYCOM 1/100° simulation. Figure 39 shows the presence of small-scale anticyclonic and cyclonic eddies along the coast of Cuba, with offshore jets forming in between, similar to those observed during the 2016 survey.

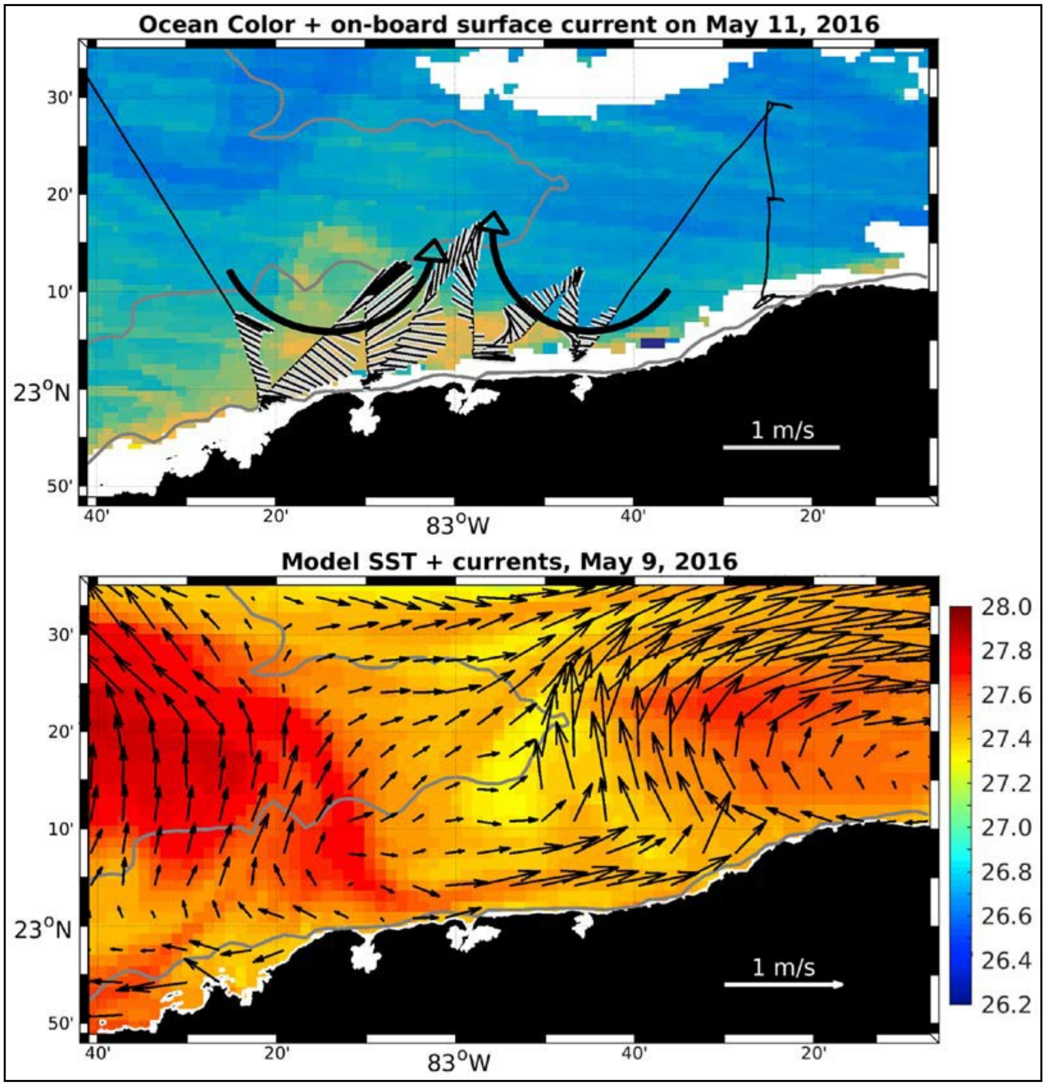

Figure 38. Chl-*a* and surface ADCP current vectors (upper) on 11 May 2016 and SST (lower) on 9 May 2016.

ACDP current vectors are black and grey lines (see figure for reference vector) with the large black round arrows illustrating the current circulation. SST) (°C, colors) and surface currents (black arrows, see reference arrow over Cuba) are from the GOM-HYCOM near-real-time simulation at 1/50°.

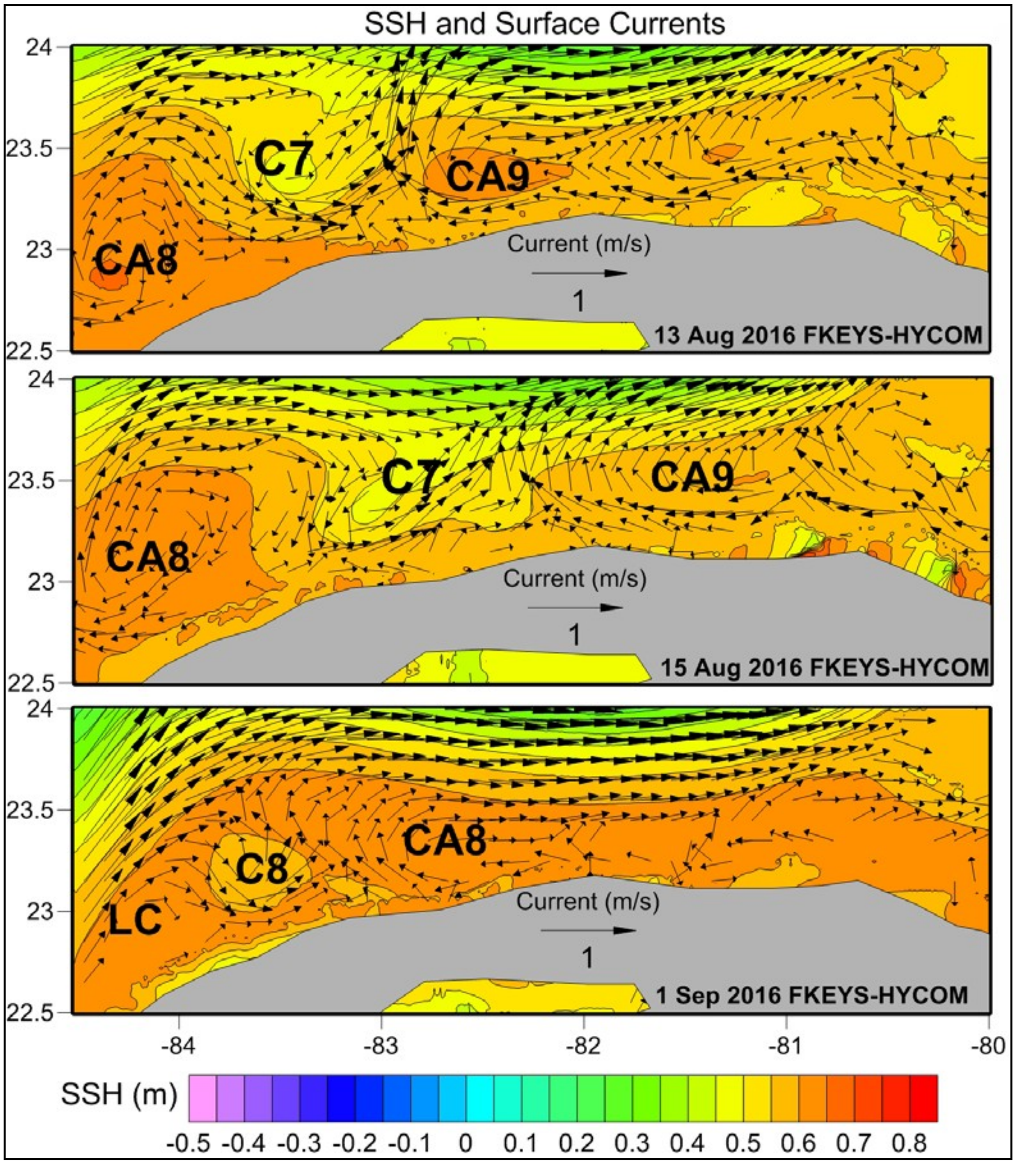

Figure 39. Simulated SSH and surface currents in late summer 2016: 13 August (top), 15 August (middle) and 1 September (bottom).

SSH (m, in colors) and surface currents (black arrows, see reference arrow over Cuba), from the 1/100° FKEYS-HYCOM simulation. CA = CubAN anticyclonic eddy; C = cyclonic eddy; and LC = Loop Current. Adapted from Kourafalou et al. (2017).

1.3.5.4.2 Biology

During the 2015 cruise, larval fish distributions were concentrated around areas of high productivity, such as Jardínes de la Reina and Guanahacabibes, as well as the northwest Cuban coast (Figure 40). In addition, high abundances were found at stations along the north coast of Cuba and south of Cay Sal Bank. Tunas, snappers, and parrot fish dominated the ichthyofauna, with large densities of snapper (>1,000 m^{-3}) collected at shallower (<200 m) inshore stations in the south and along the northwest coast. Lion fish (*Pterois* spp.) were relatively common in the ichthyofauna with higher numbers found to the south, but also present along the northwest coast of Cuba. *Thunnas* spp. were captured throughout the area, and skipjack larvae were caught at 61 of the 185 stations (33%), whereas blackfin larvae were caught at 130 stations (70%). Larval abundance of skipjack larvae was highest off Mexico and in the Yucatan Channel (Figure 41, upper panel). Abundance of blackfin larvae was highest off the northern coast of Cuba, but high concentrations were also found in the Caribbean Sea between the Isla de la

Juventud and Cabo Cruz (Figure 41, lower panel). Larval abundance of both species was lowest off Jamaica.

Abundance of skipjack larvae was greater at night than during the day. This finding suggests that skipjack exhibit some form of diel vertical migration. Thus, although the gear used works well to capture other tuna species, oscillations to a deeper depth may work better to capture skipjack larvae. Abundance of blackfin larvae increased as SST increased from ~26.75 to ~28.5 °C and decreased as chlorophyll concentration increased from ~0.068 mg/L to 0.080 mg/L, at which point larval abundance declined. Bluefin tuna were not a significant part of the tuna ichthyofauna and their distribution will be described in a later publication.

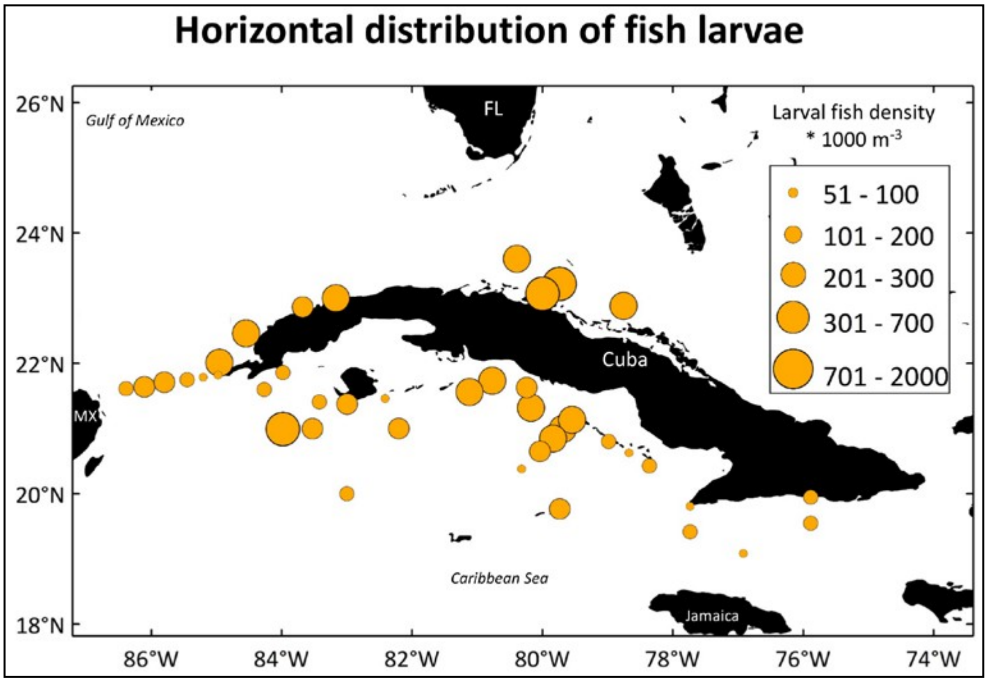

Figure 40. Distribution of larval fish from the 2015 cruise.

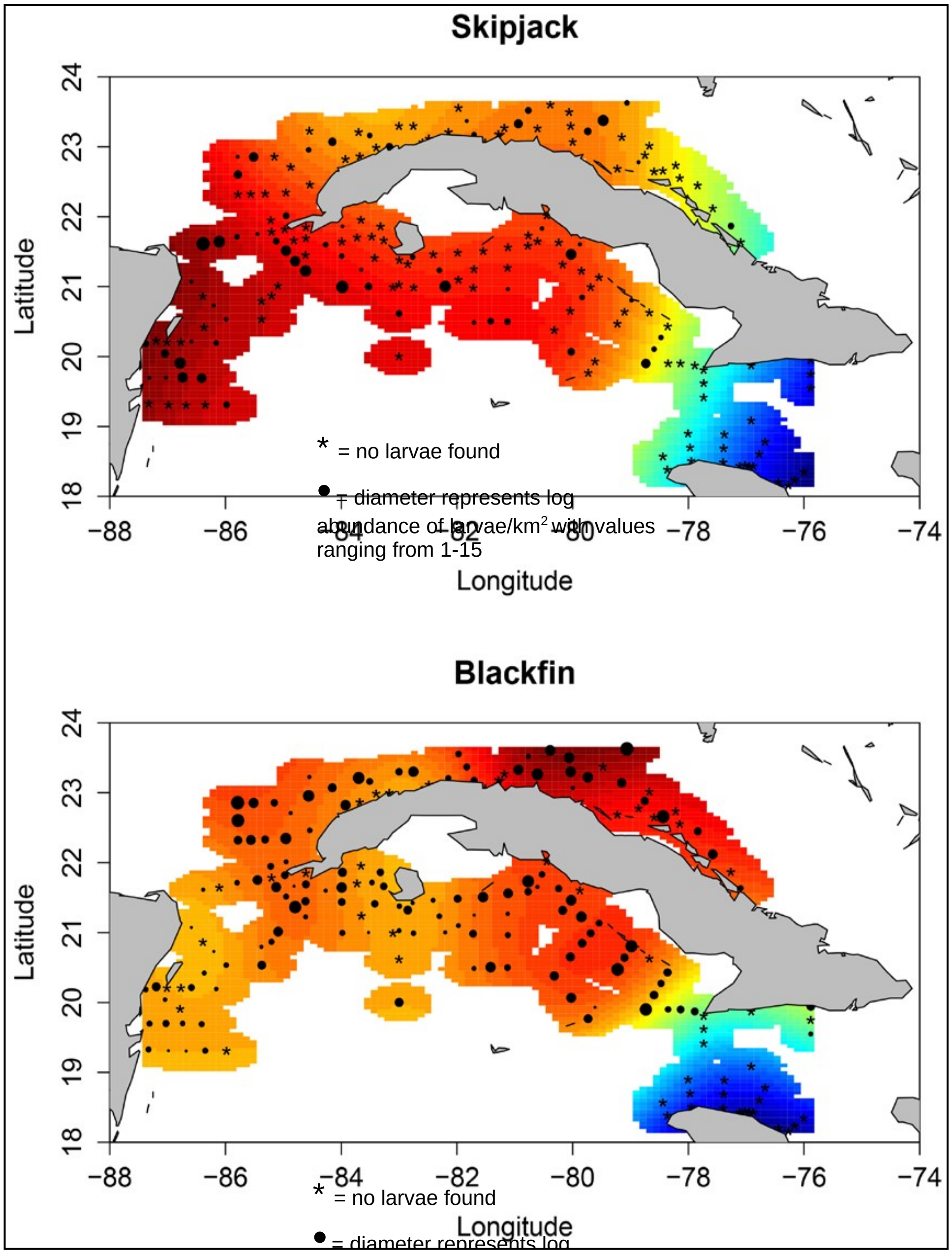

Figure 41. Location and abundance of skipjack and blackfin tuna.

1.3.5.5 Conclusions

Larval transport, dispersal and oceanographic connectivity are, generally, poorly understood. Even less is known about dispersal curves, behavioral components, and temporal and spatial variability of marine larvae. Larvae are entrained in western boundary currents, such as the Gulf Stream, as evidenced by the tropical fauna found seasonally as far north as Massachusetts (Robins et al. 1986). Reef fish larvae are also found in ichthyoplankton samples collected in LC waters in the northern GOM. However, the degree to which tropical larvae are dispersed poleward by ocean currents is unclear. Transport pathways between the waters off Yucatan and Cuba (including fish spawned south of Cuba) and the Florida Keys could be as short as 1–5 days. Results from these cruises and ancillary data from drifters and remote sensing show that the study areas—coastal Yucatan and Cuba, the GOM, and the Florida Keys reef tract—are oceanographically connected, with relatively rapid transport time-scales. Furthermore, eddies and gyres may play an important role in establishing the relevant time and distance scales of connectivity. Such direct physical connectivity by means of ocean currents between the highly migratory species, such as tuna, as well as coral reef biota of these geographically separated spawning grounds, may have an important influence on the degree of biological connectivity between regional populations of ecologically and economically important tropical marine species. As noted in the introduction, these two research cruises provide a snapshot of the ecology and physical processes of the region, but do not begin to unravel the complexities of the biophysical interactions affecting larval transport and exchange in this area.

However, the international collaboration between Mexico, Cuba and the United States allowed significant gains to be made in identifying basic processes, larval fish distribution, and the physical processes that act to control the strength of biological connections between these areas.

1.3.5.6 Acknowledgments

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1.3.6 Nonlinear Dynamics Can Shed Light on the Understanding of Transport Processes in the Southwestern Gulf of Mexico

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1.3.6.1 Abstract

The purpose of these notes is to acquaint GOM researchers with recent results that improve our knowledge of transport processes in the GOM using nontraditional tools, describe how much has been achieved, and identify what aspects remain to be understood especially in the southwestern GOM and the mechanisms for achieving the needed understanding. The exposition is largely biased toward the personal interests of the authors, some of whom have been actively involved in developing these new analysis tools.

1.3.6.2 Background—Transport Processes

The emergence of organized patterns such as filaments or eddies of different sizes and shapes in the distribution of tracers on the surface of the ocean (like temperature, salinity, pollutants or plankton) suggests the existence of an underlying material or Lagrangian (i.e., composed at all times by the same fluid elements) skeletal structure responsible for shaping lateral mixing into such patterns. The building blocks of the hidden Lagrangian skeleton of the surface ocean circulation are given by unique material lines, called "Lagrangian coherent structures" or LCS (Peacock and Haller 2013; Samelson 2013; Haller 2015).

Recent developments have occurred in an area that lies at the interface between nonlinear dynamical systems and fluid mechanics (Haller and Beron-Vera 2012; Farazmand and Haller 2013; Beron-Vera et al. 2013; Farazmand et al. 2014; Haller and Beron-Vera 2013, 2014; Haller et al. 2016; Serra and Haller 2016; Hadjighasem et al. 2016, 2017). These developments have enabled the construction of specialized deterministic techniques for the extraction of LCS from velocity fields that depend aperiodically on time (as is the case of the ocean flow) and are defined over finite time intervals (as is the case for numerical simulations, experiments or observations).

Understanding these structures is important because it helps explain the existence of a particular tracer pattern based on a firm theoretical basis (Beron-Vera 2015). But this exceeds a mere theoretical interest. Indeed, identifying LCS has very practical consequences. For instance, it allows one to carry out precise calculations of transport (of mass, heat, or salt) by eddies (Beron-Vera et al. 2013; Wang et al. 2015, 2016), including Loop Current rings (Andrade-Canto et al. 2013; Romero et al. 2016; Olascoaga et al.
2018; Beron-Vera et al. 2018). Also, these structures can be used for tracking the initial distribution of a current tracer distribution, such as for locating the nutrient source of a Florida red tide (Olascoaga et al. 2008). They are useful, too, in making predictions of how the shape of a certain tracer distribution (e.g., oil from a spill such as that produced by the explosion of the Deepwater Horizon) will change over time (Olascoaga and Haller 2012; Olascoaga et al. 2013). LCS can furthermore help identify flow regions difficult to reach by pollutants originated from sources outside of the regions, but at the same time can be heavily impacted by pollutants released within the region and provide the required isolation to favor the development of toxic blooms such as in the West Florida Shelf, the Louisiana-Texas (LaTex) Shelf, or the Yucatan Shelf (Olascoaga et al. 2006; Olascoaga 2010). LCS can, in addition, unveil persistent transport patterns from long-term circulation model simulations which are not obvious in mean flow streamlines, such as those produced by state-of-the-art models of the GOM (Duran et al.

2018; Gough et al. 2018).

Moreover, patterns formed by floating objects such as marine debris or unanchored buoys are organized around LCS underlying the flows induced by these objects (Beron-Vera et al. 2016), as has been shown for buoys deployed from airplanes in the GOM (Beron-Vera et al. 2015).

Additional developments led to probabilistic approaches to LCS which expanded the reach of the above deterministic approaches. An especially interesting aspect of these approaches is that they cover the possibility of a statistical description of the long-term evolution of a passive tracer. This includes the opportunity of identifying regions of the flow where trajectories converge in forward time, as well as the regions where those trajectories originate from (i.e., their backward-time basins of attraction), thereby determining the connectivity between separated locations in the flow domain (Dellnitz and Junge 1999; Froyland 2005). Attracting regions may be small and trap tracer for long periods of time before eventually exiting and forming what are known as almost-invariant regions. If their basins of attraction are large, they can exert great influence on the global Lagrangian dynamics. Decomposition of the surface-ocean flow into almost-invariant sets is the foundation of a dynamical geography of an ocean region, where the boundaries between basins are determined by the Lagrangian circulation itself rather than by an arbitrary geographical division. Offshore oil exploration, oil spill contingency planning, and fish larval connectivity assessments are among the many activities than can benefit from the dynamical information contained in such a geography.

Recently, Miron et al. (2017a) computed for the first time a dynamical geography for the GOM using the largest collection to date of satellite-tracked drifter trajectories. The dynamical geography revealed a basic partition of the GOM into two halves by a line running from the Mississippi Delta to the tip of the Yucatan Peninsula. In particular, the western province forms the basin of attraction for trajectories accumulating temporarily along a region of the US-Mexico maritime border. Interestingly, this region turns out to lie within Atlantic bluefin tuna preferred breeding grounds (Teo et al. 2007). On the other hand, this region includes the Perdido Foldbelt, a geological formation that is known to have great ultra- deepwater oil exploration potential. Refined partitions of the GOM dynamical geography highlighted the LaTex, West Florida, and Yucatan shelves as regions weakly communicated with the rest of the GOM.

The above techniques critically rely on the availability of flow realizations (the deterministic approaches) or fluid trajectories (the probabilistic approaches). Fluid trajectories are in many cases well approximated by satellite-tracked drifter trajectories, but these may not be available with the required spatiotemporal coverage. Also, drifter datasets are not uniform in design, so variations in water-following characteristics can be expected (Beron-Vera et al. 2016). Likewise, flow realizations may not be available with the required spatiotemporal coverage, either directly or indirectly, from observations. Direct flow observations such as those obtained from current meters are highly localized in space. A widely-used, indirect source of velocity data is given by satellite altimetry. But this can only resolve the mesoscale range of the kinetic energy spectrum, which may have substantial levels of energy in the submesoscale range (Corrado et al. 2017). High-frequency radar technology can access the submesoscale range, but it is restricted to near-coastal areas. Thus, to this date, flow realizations with the required spatiotemporal coverage can only be provided by ocean general circulation models.

A subject of intensive debate is “What is the smallest horizontal scale a model should resolve to produce reliable flow realizations for meaningful Lagrangian transport calculations?” To answer this question, knowledge of the actual shape of the kinetic energy wavenumber spectrum, E(k), is critical (Bennett 2006; LaCasce 2008). If $E(k) \sim k^{-5/3}$, the dispersion of pairs of particles (or “relative dispersion”) is local, meaning separations between pairs of particles are dominated by eddies of comparable scales. If $E(k) \sim k^{-3}$ or steeper, the dispersion is nonlocal and governed by the largest eddies in the k^{-3} range. Thus, when dispersion is local, deterministic transport calculations are essentially hopeless because a model would have to resolve the velocity field all the way into the submesoscale range. In that range, state-of-the-art, primitive-equation (i.e., hydrostatic) ocean general circulation models are not valid, and the reliability of simulations based on such models is uncertain (McWilliams 2008). But if, on the other hand, the interest is in describing transport statistically, then the situation is less pessimistic: a coarse representation of the velocity field with the addition of diffusion may be sufficient. By contrast, if dispersion is nonlocal, low- resolution model simulations can be enough for producing meaningful deterministic transport calculations.

Local dispersion produces small scale "billowing," as with smoke from a stack, while nonlocal dispersion results in filaments. Particle dispersion can thus be used to infer aspects of the energy spectrum. This has been attempted in the GOM using satellite-tracked drifters, mainly deployed in the northern part of the GOM. LaCasce and Ohlmann (2003) examined "chance pairs" of drifters (i.e., drifter pairs, which while not deployed together, approached one another after deployment) from the Surface-Current and Lagrangian drifter Program (SCULP) (Ohlmann and Niiler 2005) and found nonlocal dispersion below the deformation radius, which is approximately 45 km in the GOM (Chelton et al. 1998). Supporting evidence, using pair separation probability distribution functions (PDFs), was obtained by LaCasce (2010). However, using different measures (the second order longitudinal velocity structure function and the separation averaged relative diffusivity) with original drifter pairs from the Grand LAgrangian Deployment (GLAD) in the vicinity of the DWH oil spill site (Olascoaga et al. 2013), Poje et al. (2014) concluded the dispersion was local, from a few hundred meters to several hundred kilometers, implying a shallower kinetic energy spectrum. Analyzing the same drifter dataset using various measures of dispersion, Beron-Vera and LaCasce (2016) obtained ambiguous results, some indicating local dispersion (in which pair separations exhibit power-law growth) and others suggesting nonlocal dispersion. The reason for the discrepancies across the measures was attributed in part to inertial oscillations, which affected the energy levels at small scales without greatly altering pair dispersion, and also to the fact that the GLAD drifters were launched over a limited geographical area, producing few independent realizations and hence low statistical significance.

Relative dispersion was also investigated in the southwestern GOM, but only using chance pairs (Zavala- Sansón et al. 2017). The set of drifters used was part of a long-term program of oceanographic observations funded by PEMEX and conducted by CICESE. Zavala-Sansón et al. (2017) found nonlocal dispersion from the analysis of time-dependent measures (separation PDFs and second and fourth moments) versus local dispersion from the analysis of distance-dependent measures (e.g., separation- averaged relative diffusivity). In this case, the reason for the discrepancies might be attributed to limited geographic sampling and, consequently, lack of statistical independence. But these discrepancies may well reflect differences in how quickly chance pairs lose their "memory" of their initial condition, which depends on the correlation between their initial separation and velocity (Babiano et al. 1990).

1.3.6.3 Transport Processes in the Southern GOM

The above studies have shed some light on the nature of relative dispersion, and consequently the shape of the kinetic energy wavenumber spectrum in the GOM. Further research is still needed to constrain it better, especially in the southwestern GOM, where the uncertainty is larger due to poorer sampling compared to that in the northern and northwestern GOM. But why study transport processes in the southwestern GOM? There are a number of important reasons.

The southwestern GOM constitutes a large subsystem of the much larger GOM marine ecosystem, a mixture of ecological characteristics of temperate and tropical environments (Kumpf et al. 1999). It receives discharges of nutrients and dissolved organic material from many natural river systems and a network of coastal lagoons and estuaries, which favor the development of environmentally- and biologically-diverse coastal systems. Coral reefs with variable morphology and development are found on the East Mexico Shelf, which narrows from a width of about 90 km to 6 km from north to south and then widens to~150 km or more as it encounters the Yucatan Shelf. The variable morphology of the reef system is mainly attributed to the sedimentary gradient on the shelf, ranging from terrigenous to biogenic materials (Lara et al. 1992; Ortiz-Lozano et al. 2013). The physiographic complexity of the region is important in modifying flows generated by different components of the circulation, supporting retention and survival of the reefs (Salas-Pérez and Granados-Barba 2008).

The mesoscale circulation of the southwestern GOM is influenced by Loop Current rings. Loop Current rings are anticyclonic eddies of 150–300 km in diameter that pinch off from the Loop Current and travel westward across the GOM nearly reaching the western margin (Vukovich 2007). These eddies do not seem to penetrate south of 22º N into the Bay of Campeche, where a semipermanent mesoscale cyclonic circulation known as the Campeche Gyre tends to develop (Monreal-Gómez and Salas de Leon 1997). Based on oceanographic data, Vázquez de la Cerda et al. (2005) documented the Campeche Gyre and argued that it is seasonally forced by the wind, but the actual drivers of the gyre are still largely unknown (Cordero-Quiros 2015). Using surface drifters and moorings, Pérez-Brunius et al. (2013) found that the Campeche Gyre tends to reside on the western side of the Bay of Campeche, possibly topographically constrained by the continental shelf break. An additional important characteristic of the southwestern GOM is the presence of intense currents along its western margin that can flow in either direction. On the continental shelf, the direction of the flow depends on the along-coast winds or the presence of eddies interacting with the shelf (Zavala-Hidalgo et al. 2003; Dubranna et al. 2011). Along the continental shelf break, a western boundary current flowing northward is present throughout the year, driven by the wind stress curl over the northern GOM (Sturges 1993; DiMarco et al. 2005). Its intensity varies with the seasonal variability of the wind curl and by the presence of mesoscale eddies on synoptic scales (Dubranna et al. 2011). In addition to along-shelf transport, transport tends to develop across the narrower portions of the continental shelf, where the East Mexican Shelf meets the Yucatan Shelf and the southern LaTex Shelf, and varies during the year depending on the wind forcing (Zavala-Hidalgo et al. 2014).

Due to its high biodiversity and living resources as well as urban and industrial expansion and energy resources, the southwestern GOM has been considered strategic in national plans for the social and economic development of Mexico. The discovery of fossil fuel reserves in the seabed of the Bay of Campeche in the 1970s promoted the rapid expansion of the Mexican oil industry in offshore waters. Large regions over the Yucatan Shelf are currently home to numerous offshore rigs and oil platforms, exposing the southwestern GOM ecosystem to potentially negative environmental impacts.

Indeed, tropical marine systems maintain a delicate ecological balance among their different components that can easily be disrupted by anthropogenic disturbances. Major oil spills are prone to cause severe and long-term ecological effects (Soto et al. 2014). An example of an accidental oil spill in the region is the one produced by the explosion of Ixtoc I, an exploratory oil well drilled by a semisubmersible drilling rig in waters nearly 50 m deep. In June 1979, the well suffered a blow-out resulting in the world’s first massive oil spill occurring in offshore waters of a tropical environment. More than 3.4 million barrels of crude oil were released into the southwestern GOM over nearly 9 months (PC-EESC 1980). Growing concern has been building ever since this ghastly oil spill because of the harmful environmental effects on a marine ecosystem that was once known for its pristine characteristics before the rapid expansion of oil exploration and the extraction of fossil fuels in the area.

The regions of oil exploration have extended in recent years further away from the Yucatan Shelf and into the southern LaTex Shelf, expanding the areas exposed to potential anthropogenic stress beyond Mexican waters. Indeed, the Mexican national oil company made a major discovery in the Perdido Foldbelt in 2012. The Perdido Foldbelt is a geological formation that encompasses an area of nearly

40,000 km^2 across the maritime border between the United States and Mexico, which is a rich discovery of crude oil and natural gas that lies in water that is close to 2,500 m deep. On the US side of this rich oil-gas reservoir, international oil companies are already producing large amounts of oil and planning expansions.

Hence, it is of utmost interest for the environment and the Mexican and US economies to study the short- and long-term fate of pollutants released in the southwestern GOM. Specifically, it is quite relevant to determine under what circumstances a tracer will remain in the south or otherwise will spread and move northward, identifying scenarios in which either or both situations could take place. The nonlinear dynamics tools discussed above have been designed to specifically address these kinds of problems.

For instance, they can be used to identify in an observer-independent fashion Loop Current rings with coherent material boundaries at the time of generation and track them across the GOM until their demise. Because of the potential of these mesoscale rings in shaping the circulation in the southwestern GOM, it is of interest to determine with precision their fate as they reach the continental margin. Do they migrate northward or southward upon encountering this margin? Are there offspring byproducts of these encounters? What is their precise fate? These and many other pertinent questions may be answered by applying deterministic LCS detection designed to reveal coherent Lagrangian eddy motion (Haller and Beron-Vera 2013; Haller et al. 2016).

Deterministic LCS detection can also be utilized to unveil cores along LCS with uninterrupted attraction (Olascoaga and Haller 2012; Olascoaga et al. 2013). When applied in backward time, this so-called LCS-core detection can be used to make predictive assessments of the evolution of a tracer patch. More specifically, it can be used to predict sudden changes in the shape of an oil slick from a spill with a few days of anticipation using velocity information up to the moment of the assessment without the need of predicted ocean velocities beyond that moment.

The connectivity problem can be tackled using the probabilistic LCS methods (Froyland et al. 2014; Miron et al. 2017b). Determining ecological reserves can benefit from the information contained in the dynamical geographies determined by the Lagrangian circulation that these techniques can help construct. A question that the probabilistic techniques can elucidate is the extent to which the southwestern GOM reefs are connected with the LaTex shelfbreak reefs. Likewise, regions that may be more susceptible to ecological damage for being isolated can be detected using the probabilistic LCS methods. Where does pollution tend to accumulate? Where are the sources of pollution located? These are important questions since there is a growing consensus that chronic oil pollution caused by inshore and offshore routine operations is eventually as harmful to the environment or more harmful than accidental oil spills.

In all cases, as noted earlier, reliable flow realizations or sufficiently dense Lagrangian observations (buoy trajectories) are critical. The latter can be used directly to feed the probabilistic LCS methods and reveal 2-D aspects of the upper-ocean Lagrangian circulation (if surface drifters are considered) or 3-D aspects of the deep-ocean Lagrangian motion (if submerged float trajectories are analyzed). These data in large amounts are fundamental to elucidate the essential features of oceanic turbulence, and validate ocean general circulation models that assimilate available observations including altimetry data. That the latter may or may not be a reliable source of velocity data in the southern GOM, given the presence of the wide Yucatan Shelf, needs to be thoroughly assessed. All this demands a comprehensive observational program.

Beron-Vera and LaCasce (2016) have provided guidance for making surface drifter deployments in such a way that they produce statistically-independent pairs of trajectories which are meaningful for relative dispersion studies. The deployments must be planned to account for the fact that the spatial decorrelation scale tends to be on the order of the Rossby radius of deformation, about 45 km in the GOM. This indicates that well-spread drifter pair deployments should be preferred over localized deployments. If this is not feasible in practice, a similar effect may be achieved by repeated pair deployments at intervals longer than the temporal decorrelation scale, which is of one day or so at the surface (LaCasce 2008). Numerical experimentation suggests that a very large number of independent pairs of trajectories is not needed to produce robust separation statistics. On the order of 100 pairs may be enough to achieve the goals. Existing oil rigs might be used as platforms for coordinated, repeated drifter pair deployments.

Longer spatial and temporal decorrelation scales can be expected deeper in the water column. The Lagrangian circulation in the deep ocean is by far much less understood than the surface ocean Lagrangian circulation. Some understanding has been recently gained from the analysis of submerged floats. Pérez-Brunius et al. (2017) describe an abyssal cyclonic circulation in the western basin, and Miron et al. (2018) construct a Markov-chain model that reveals a partition into various weakly communicating deep-flow regions. Deployment and analysis of additional submerged floats is required to shed further light on the picture, including the tendency of floats deployed inside the deep GOM domain to remain within the domain (Pérez-Brunius et al. 2017; Miron et al. 2018) in connection with ventilation of the abyssal layer (Rivas et al 2005).

Dense mooring arrays across the continental shelf recording velocity using ADCPs and hydrographic variables over long periods of time in a sustained manner would ideally complement the drifting buoy dispersion analyses and together would help determine the structure of the kinetic energy spectrum in the region. The information gathered would provide metrics for model performance and eventually could be used in model development.

The near-coastal Lagrangian transport may be monitored by high-frequency radars. While plans exist to establish a network of radars along the southwestern GOM, validation of the velocity fields inferred from the radar measurements is critical. This can be achieved by satellite-tracked drifter deployments and possibly dye releases in the coastal environment.

In summary, the southwestern GOM offers a number of opportunities for using nonlinear dynamics techniques to advance knowledge in transport processes. The knowledge gained would be very helpful for guiding activities such as those dealing with preventing and/or ameliorating the effects of accidental as well as chronic oil spills or blooms of toxic algae, or for supporting stock assessment efforts and management decisions for fishing regulations. These are all matters of concern for both the Mexican and US societies, so collaboration between the two countries should be encouraged for their mutual benefit.

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1.3.7 Data Gaps for the Benthos of the Deep-Sea Gulf of Mexico

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1.3.7.1 Abstract

Performing research on the deep-sea benthos is difficult and expensive, because it requires larger sea-going research vessels and heavy equipment to sample the bottom. Also, deep sea habitats are large, covering greater than 66% of the Earth's surface. The result is that only a tiny fraction of the deep sea has ever been sampled, and there are many data gaps. However, two gaps are critical because there is a lack of understanding of temporal dynamics, and taxonomy of deep-sea organisms. While past dogma suggested that the deep sea was stable, the influence of the Mississippi River on sediment and particulate flux, which can drive benthic dynamics, indicates there is likely temporal variability in the GOM. Two historical benthic data sets were combined to create a 13-year time series, and there was year-to-year variability in meiofauna and macrofauna abundances in the GOM deep sea. Community structure is the most fundamental piece of information about any ecosystem, yet there is a profound lack of knowledge about the species diversity of the GOM, particularly for small benthic infauna. Often, only 25% to 40% of taxa in a sample can be named. Ironically, research is racing ahead to identify environmental DNA in water and sediment samples using metagenomic and barcoding techniques, even though we don't know what is there. Thus, we are vastly underestimating the biodiversity of the Gulf and need increased effort in identifying and cataloging the species found.

1.3.7.2 Introduction

The deep sea benthic habitat is large, but the most efficient way to sample it is to drop a box core, grab, or multicore device from a ship. This sampling constraint confers two implications: the limitation of sampling devices means that we have sampled only a tiny fraction of the deep sea, and the high costs of ships means that it is expensive and difficult to obtain samples. Consequently, we know very little about deep-sea benthic habitats, even though they are the largest on Earth, because they are relatively inaccessible. The GOM deep sea benthic environment is especially interesting because it is a complex, heterogeneous environment where sediment transported by the Mississippi River dominates (Balsam and Beeson 2003). Soft-bottom sediments and communities are the dominant habitat on shelves and in the deep-sea, but there are some salt domes (or salt diapirs, which are emergent structures) that play a role in supporting hard-bottom communities (Love et al. 2013; Rezak et al. 1985). The hard substrate (including artificial reefs, oil and gas platforms, and natural reef or rock substrates) can act as fish habitat in the United States Exclusive Economic Zone of the GOM and accounts for about 4% of the total area of the bottom (Froeschke and Dale 2012), which implies that 96% of the Gulf is soft-bottom habitat. So, while it would be expected that there are many data gaps, the focus here is on two: temporal dynamics and taxonomy.

1.3.7.3 Temporal Change

The deep sea is uniformly dark and cold (4–5 °C) and relatively isolated from the surface water column. Thus, the dogma of deep-sea research is that the deep sea is a constant, invariant environment. This led Howard Sanders (1968) to propose the stability-time hypothesis to explain the high diversity found in deep-sea environments. Though the stability-time hypothesis does not adequately explain all deep-sea diversity patterns, the idea that the deep sea is generally more stable than shallow-water systems over time has persisted. The deep sea is thought to be a stable environment with less frequent changes in physical and chemical conditions compared to shallow, coastal habitats.

More recently, it has been discovered that pulsed events can drive deep-sea dynamics (Smith 1994). These kinds of events include biogenic mound building, benthic storms, phytodetritus pulses, and whale falls. In the GOM, the influence of the variability of the Mississippi River provides a plausible mechanism for both seasonal and year-to-year changes over time.

In addition, there are at least two datasets, with at least three years of data each, indicating that deep sea stability may not be true in the GOM. The Deep Gulf of Mexico Benthic Program (DGoMB) provides a case study (Rowe and Kennicutt 2008, 2009). A total of 43 stations were sampled during the first cruise (May–June 2000), seven stations were reoccupied during the second cruise (June 2001), and during the third cruise (June 2002), two stations were reoccupied, and five stations were sampled in the abyssal plain. Seven stations (C7, MT1, MT3, MT6, S36, S41, S42) were sampled twice (in 2000 and 2001), and one station (MT3) was sampled three times. Using just the two years where seven stations were sampled, provides a simple two-way analysis of variance (ANOVA). One important finding is that there are differences in meiofauna ($p = 0.0034$) and macrofauna ($p = 0.0085$) total abundance between the two years, but there is no significant "cruise-station" interaction, meaning that change across the area happened in similar ways at all stations. During the DWH Natural Resource Damage Assessment (NRDA), 34 stations were sampled during the fall 2010, spring 2011, and spring 2014 cruises (Reuscher et al. 2017). Differences in abundance were found for macrofauna ($p = 0.0042$), but not for meiofauna ($p= 0.5797$). One NRDA station (FFMT3) was the same as DGoMB station MT3 that was sampled twice. A plot of macrofauna and meiofauna abundance indicates change over time (Figure 42). These results indicate that there is year-to-year variability in the GOM deep sea.

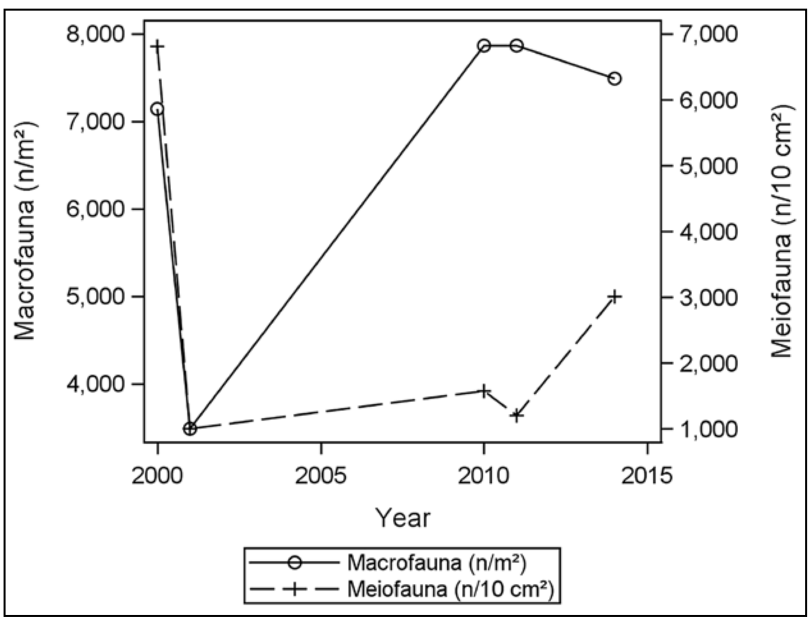

Figure 42. Macrofauna and meiofauna average abundance at station MT3 (same as FFMT3).

Location 28.218692 N, -89.491714 W, 1,002 m depth. Source: P. Montagna.

These time series studies illustrate an important point: the deep sea is not static, and any sampling program must be able to distinguish natural year-to-year variability from changes due to other events, such as oil spills. Temporal variability in benthic abundance also occurred over a nine-year period in the deep sea of the northeast Atlantic Ocean, and it is thought to be a result of interannual differences in food supply (Soto et al. 2010). In addition, the cruises in the NRDA study were deployed in fall and spring, so there is also the possibility that the NRDA study results are due to seasonal variability and not just year- to-year variability, because we really don't know if there is seasonality in benthic community composition in the GOM.

It is reasonable to hypothesize that both seasonal and year-to-year variability exists in GOM benthic communities. Seasonality could be driven by discharge from the Mississippi River, which is higher in spring than at other times of the year. The surface waters have supplies of nutrients in spring that could lead to spring blooms and thus greater deposition of organic matter in spring, which would fuel increased benthic metabolism and could change benthic structure and function. The most obvious result of this process is the large hypoxic zone that forms off Louisiana every summer in shallow shelf waters (Rabalais et al. 2002), with interannual differences in the size of the hypoxic zone (Turner et al. 2012). Year-to-year variability could be driven by any one of three phenomena or a combination of all: inter- annual differences in weather that drives runoff and river discharge; interannual variability in the timing, location, and intensity of the Loop Current; and interannual variability in the number, frequency, and strength of tropical storms. We also know that interannual variability in weather is driven by teleconnections of the global climate system because the frequency of El Niño drives increased river flows to the coast in Texas (Tolan 2007), Louisiana (Piazza et al. 2010), and Florida (Beckage et al. 2003). The increases in flow rates likely increases export from the Mississippi River, which can drive oceanic processes in the deep sea. The El Niño and/or La Niña oscillations are known to drive benthic community structure in the northeast Pacific Ocean (Ruhl and Smith 2004).

Because we know little about temporal variability in the GOM deep sea, it is impossible to be certain that we can distinguish change due to natural variability from change due to anthropogenic effects. More study of this phenomenon is needed to complete our understanding of the drivers of living marine resources in the Gulf.

1.3.7.4 Taxonomy

Perhaps the most fundamental piece of knowledge about any ecosystem is: "What is there?" Yet, we have a profound lack of knowledge about the species diversity of the GOM. Of course, the lack of taxonomic information is less true for the large organisms, but the lack of knowledge for the smaller organisms is acute, especially for the deep-sea benthos. There is an important compendium of the biodiversity of the Gulf (Felder and Camp 2009), which spans 1,312 pages and covers all Gulf habitats and taxa. However, Felder and Camp note that taxonomy is a neglected scientific activity that requires renewed priority because of global climate change, declining diversity, exploitation of living marine resources, habitat destruction, and other nonsustainable practices by humans. It is estimated that as much as 80% of the species on earth remain unknown to science, and the problem, of course, is that much biodiversity could be lost before we even know it exists (Costello et al. 2010).

In general, the lack of taxonomic understanding in the GOM is a problem, because species diversity is a very sensitive indicator of change in the deep sea (Montagna et al. 2013; Montagna et al. 2017; Reuscher et al. 2017). Therefore, a lack of knowledge as to what is there impedes our ability to assess the state of the deep sea. This problem is not new and was pointed out previously (Carney 2001). Further, the GOM deep sea is recognized as one of the most threatened on earth because of the cumulative impacts of many variables (Costello et al. 2010).

The DGoMB study (Rowe and Kennicutt 2008, 2009) provides one of the very few large-scale spatial surveys of the GOM deep-sea benthos that are known to species level. A large effort was made to send samples or voucher specimens to taxonomists throughout the world for the many diverse taxa. However, only 40% (207 of 517) of polychaete species and 25% (31 of 124) of amphipod species found in the DGoMB study could be identified to species. Because of the lack of information at the species level, and the large expense to make these identifications, it is often the case that specimens are identified to the lowest taxonomic level possible. For the GOM, this was generally to the family level during the NRDA investigations (Montagna et al. 2013; Montagna et al. 2017; Reuscher et al. 2017). However, the lack of understanding of the diversity of these lesser known families is leading to a vastly underestimated biodiversity of the deep GOM (Reuscher and Shirley 2014).

Though it is well recognized that the gap in biodiversity knowledge is critical, there is no evidence of increased resources to identify and inventory marine biodiversity (Costello et al. 2006). There is a critical need for more taxonomists and species identification guides. These are the most basic requirement for studying biodiversity. In contrast, there is a large new field of genomics, and environmental DNA, such that standard phylogenetic markers are capable of recovering sequences from a broad diversity of eukaryotes and prokaryotes (Drummond et al. 2015). However, a major challenge for gene surveys is the accurate identification of biological taxa across multiple samples, and the ability to quantify the absolute abundance of individuals based on a sequence read (Bik et al. 2012). This leads to two difficult problems:

(1) What good is it to know the DNA in two areas is different, but not know why?, and (2) How can we calculate a true diversity index if we don't know the proportional representation of the species present?

1.3.7.5 Conclusions

Tthere are many data gaps for the deep sea, especially for the deep-sea benthos, including (but not limited to) geographic coverage, understanding variability of sedimentation rates important for controlling food supplies, identifying ecosystem services and values supplied by the deep sea, and rates of geochemical and metabolic processes. While it would be important to examine all the data gaps that exist, here it is argued that the two most critical data gaps are understanding temporal dynamics and increasing the technical capacity to identify species diversity. Based on studies around the world and in the Gulf, it is likely that there is seasonal and interannual variability in the Gulf, which has important implications in an environment threatened by global change and increasing human uses. Understanding the dynamic of temporal change is a key data gap. We also know that we are vastly underestimating the biodiversity of the Gulf and need increased effort in identifying and cataloging species. However, the trend over the last 30 years has been for decreased support for systematics and taxonomy, though we still don't know what is there. It is important to reverse this trend before we lose things we didn't know we had.

1.3.7.6 References

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1.3.8 Avian Sentinels of "One Health" for the Gulf of Mexico

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1.3.8.1 Abstract

The GOM is a complex ecosystem with a rich diversity of flora and fauna. The past few decades have brought dramatic changes to the GOM coastal ecosystem, with rising contamination from environmental chemicals associated with catastrophic events, including hurricanes and human-made crises. Assessing the impacts and interventions for future natural or human-made events remains challenging. The full implications of events such as Hurricane Harvey, which wreaked havoc in a region already heavily impacted by contamination from the DWH oil spill, are complex and ongoing. Understanding vulnerable areas associated with flooding and waterways are critical to maintain human health, wildlife populations, and the ecosystem. Coastal communities have been severely impacted by both natural and human-made events and their recovery relies on community and ecosystem resilience to achieve stability and nurture growth. Economic drivers and ecosystem attributes in these communities focus on fishing, oil, gas and chemical industries, ports, tourism and a range of other industries, as well as leisure activities that are fundamentally important for the health and well-being of individuals and the social and/or psychological health of human communities. Birds are important members of this ecosystem dynamic, not just for their roles in maintaining natural ecosystem balance, but also for providing direct benefits in the form of economically important leisure activities (e.g., hunting, birdwatching), and a more generalized sense of well-being for those who engage in "enjoyment of nature" activities. The concept of "One Health" articulates the close interrelationship between ecohealth and human health, particularly acknowledging not only the relationship of environment to human well-being, but also the critical co-dependence of the human population with our world. Birds provide sentinel wildlife species to assess "One Health" and the potential risk from exposure to environmental chemicals for individuals, species, and ultimately populations. Birds are often sensitive indicators of environmental damage, so understanding the health of GOM birds in relation to environmental stressors which include chemical contaminants, and the short- and long-term impacts of these stressors, can provide tremendous insight into the status of these key wildlife populations and a mirror into the "One Health" of the ecosystem. The GOM contains large numbers of resident and migratory bird species that rely heavily on the Central Flyway for spring and fall migrations. The quality of these habitats and resources has implications for human health and the economic well-being of coastal communities. This review will focus on the status of selected sentinel species of birds in the GOM, with attention to environmental challenges and impact for the "One Health" of wildlife and humans.

1.3.8.2 Introduction

The DWH oil spill, resulted in widespread contamination of GOM offshore and coastal regions. Data have been collected pertaining to wildlife impacts, and it is critical that these data be compiled, synthesized, and modeled to determine impact to, and resilience of, the ecosystem. Some studies have examined mechanisms and targets of the contaminants and potential risk to wildlife, providing valuable information regarding the potential for adverse outcomes from exposure in wildlife and potential for impacts to the ecosystem. Studies such as these are especially important because effects on wildlife health and the ecosystem are closely allied to that of human health and healthy communities. This concept of "One Health" is key to understanding the interrelationship between ecosystem health and that of associated human communities, such as coastal communities along the GOM, and for ascertaining potential risks to humans.

In addition to the dangers of contaminant exposure from oil and/or gas and other human industries, another critical factor to One Health of the ecosystem and human communities is natural disasters. The recent flooding from Hurricane Harvey extensively impacted the GOM and its coastal areas and may have had catastrophic ecosystem impacts. Moreover, inland regions can also be heavily impacted from such extreme rain events due to direct effects from runoff into rivers and associated flooding, as well as the accumulating volume of water carried downstream, changes in salinity and height of water tables, watercourse redirection, and soil erosion. Runoff from agricultural, residential, and industrial areas often carries substantial loads of environmental chemicals, which then travel through the environment and increase the risk of exposure to humans and wildlife. Additionally, there may be impacts due to spread of disease-causing bacteria and toxic algal blooms that not only affect health, but that can cause severe impacts on industries such as oyster production. These natural disasters set the context within which human-made impacts occur and are the background stressors for both wildlife and human populations, thereby impacting One Health of the ecosystem and associated communities. This review will consider the unique characteristics of avian species that make them important as sentinel species for the One Health of the GOM environment and provide an overview of the waterways and impacts of intermittent weather events affecting the region and the risk from environmental chemicals that are spread by natural and human-made events.

1.3.8.3 The Gulf of Mexico and Associated Waterways

The Mississippi River, originating in Minnesota and terminating in Louisiana is a major contributor of fresh water to the GOM, bringing with it dissolved and particulate materials (Figure 43). Of particular interest is the diversity of land use along the Mississippi–Atchafalaya River Basin. By the time the river reaches the GOM, it has collected runoff from urban and agricultural lands, creating a mixture of environmental chemicals with those already present in the GOM. Thus, it is critical to consider any exposures to mixtures of chemicals, aknowledging that there may be synergistic interactions resulting in additive adverse effects and increased risk to exposed populations. More local to the GOM, the Brazos River stretches more than 800 miles through agricultural and urban regions, with a basin having a large catchment area. The Brazos runs through Waco, Texas and traverses further through farmlands and varied landscapes on its way south to Houston and ultimately to the GOM near Freeport. During Hurricane Harvey and other widespread rain events, heavy rainfall contributed to a dramatic increase in the volume of water and debris from the upper regions of the river that were carried downstream. This greatly exacerbated the flooding in southern regions, especially as the river passed through the Houston area and south to the GOM. In addition to the Brazos River, Buffalo Bayou flows from Katy to Houston and ultimately through the Houston Ship Channel to the GOM, and also contributes large volumes of water and debris.

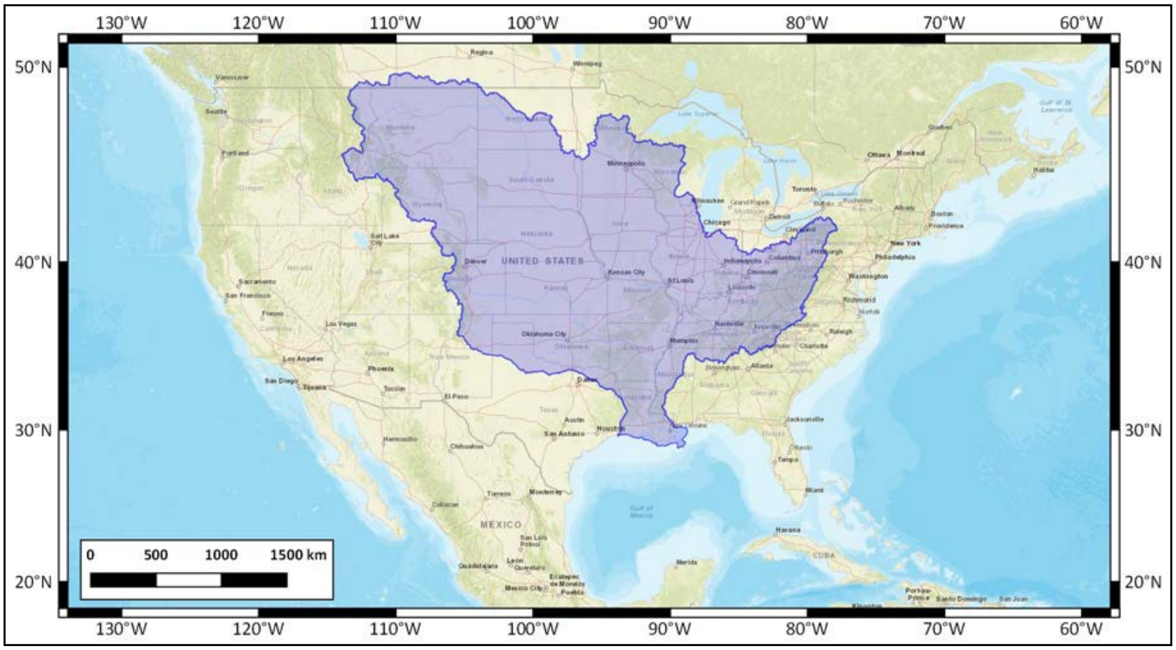

Figure 43. Mississippi River drainage basin.

Mississippi River drainage basin highlighted in blue. Drainage basin shapefile from USGS ScienceBase and basemap from Esri Basemap layers collection. Figure prepared by M. Besonen.

1.3.8.4 Industry along the GOM

A large concentration of oil and gas industry exists throughout the GOM involving all aspects of the industry from oil and gas exploration through to petroleum refineries and natural gas processing plants. A large concentration of oil and gas industry along the coast and in the GOM was in the path of Hurricane Harvey. Further, shipping and trade is concentrated in the ports of Galveston, Houston, and others in Texas and Louisiana. The DWH oil spill resulted in widespread contamination of coastal regions, including those containing oil and gas processing plants. In addition, Houston is known as the energy capital of the United States because it is home to many energy-related industries beyond refineries. A myriad of manufacturing and chemical production facilities associated with oil and gas are also located here. Further, energy-related manufacturing is concentrated in areas that would feel the impact and disruption of hurricanes and hurricane-related flooding. This has numerous implications for both the economy and human condition as well as for the ecosystem. For example, if the supply of electricity is interrupted and control and failsafe devices fail, resulting fires could release hazardous chemicals into the air/water or onto land, potentially impacting the health of humans, wildlife, and ecosystems. Although the examples given are more focused on Houston and the area associated with the Houston Ship Channel, a similar concentration of the chemical industry is also found on the Louisiana coast and at its ports as well as west to Corpus Christi, Texas. Taken together, the high concentration of oil, gas, and chemical industries in the northwestern GOM, in combination with an extreme natural event such as a hurricane, can pose a significant risk to the ecosystem and human health. A consequence of the extensive industrialization, trade, and commercialization is environmental chemical contamination. The US Environmental Protection Agency in collaboration with the National Institutes of Environmental Health Sciences (NIEHS) provides national and regional maps of identified sites of concentrated environmental chemicals (TOXMAP).

1.3.8.5 Status of Birds in the GOM

The entire coastal region of the GOM is populated by hundreds of resident and migratory bird species. According to the Texas Parks and Wildlife Department, 98.5% of the 338 species of birds considered to be Nearctic-Neotropical migrants can be observed in Texas (Online FAQ. Just over over half of the 600+ species recorded in Texas are migratory birds utilizing the Central Flyway (Figure 44, green shading). In addition, other routes utilized by migratory birds may cross over the GOM. Stopover sites along Gulf coastal areas are critical for migratory birds to successfully reach their wintering or breeding grounds. The Smithsonian's Migratory Bird Center has been tracking migrants traversing the Gulf Coast using banding, stable isotopes and tracking techniques to study long-distance migrants (. In addition, there are historical and current records through the work of agencies, interest groups, and foundations. These records in combination with the North American Bird Banding Laboratory provide an extensive and detailed resource that encompass historical and current data that will bedescribed.

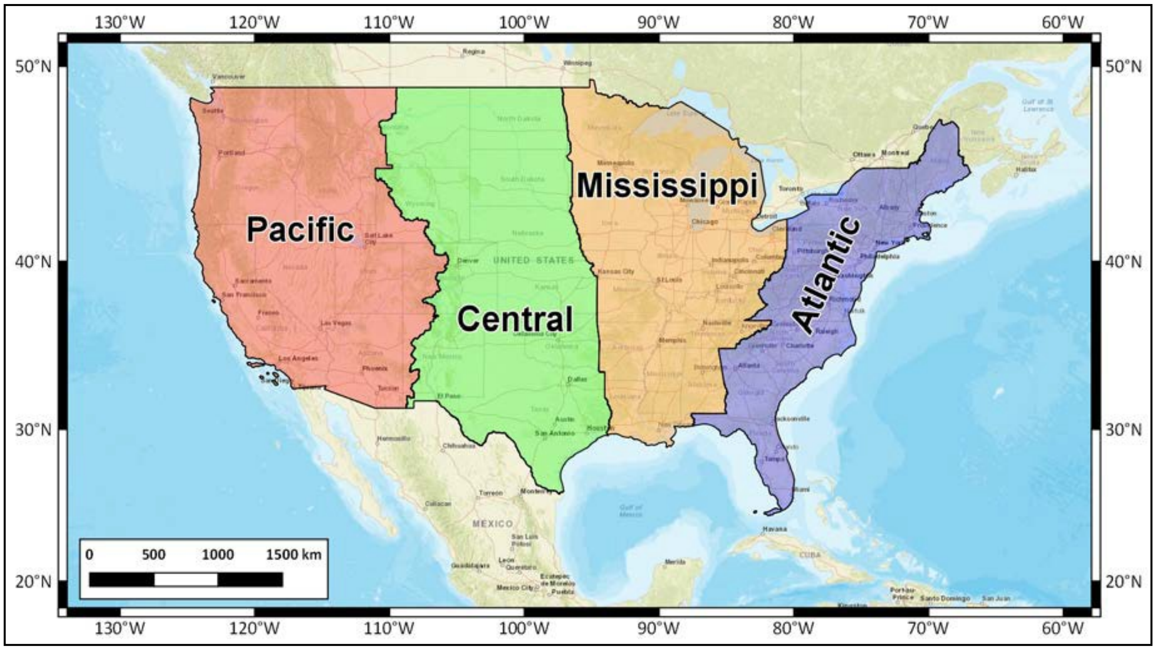

Figure 44. Migratory waterfowl flyway boundaries.

This figure shows migratory waterfowl flyways (red-Pacific, green-Central, orange-Mississippi, blue-Atlantic) over the continental United States. Shapefile for flyways is from the US Fish and Wildlife Service.) and basemap is from the Esri Basemap layers collection. Figure prepared by M. Besonen.

A large database of Central Flyway migratory bird data is available through the North American Bird Banding Laboratory that is a partnership between the US Geological Survey (USGS) and the Canadian Wildlife Service (CWS). This partnership was initiated in 1909 and formalized in 1920; information from banding permits, sightings of banded birds, and reports of deceased individuals provide long-term data with individual records on longevity and seasonal locations. The National Audubon Society has 188 years of Christmas Bird Counts with more than 22 million birds counted. The Gulf of Mexico Avian Monitoring Network (GoMAMN) also has a considerable amount of retrospective and current data on migratory and resident avian populations. These long-term monitoring projects provide large and robust pre-existing datasets that have enormous potential for modeling purposes. Integrating these data with health-related assessments provides valuable insights into short- and long-term impacts of habitat restoration on ecosystem and human health. The northern GOM is critical habitat for migratory and resident species; managers must have more information to assess the impact of habitat restoration on bird populations and health.

Habitat availability and loss due to weather events or urbanization presents major challenges for birds that reside in or migrate through the GOM (Burger 2017). It is important that dynamic changes occurring in coastal regions are integrated into risk assessment models. This includes climate change, anthropogenic activities associated with industry, urbanization, and commercialization, and other sources of contamination (e.g., oil spills), as well as natural events (e.g., tropical systems and other extreme weather events). This is especially true for endangered birds in the region, such as the whooping crane (*Grus americana*), for which the impacts of climate and habitat changes need to be considered in the context of species restoration programs. The International Crane Foundation in Baraboo, Wisconsin and Patuxent Wildlife Research Center in Laurel, Maryland have been the sites of captive breeding colonies, and these organizations support and carry out monitoring and reestablishment programs. Wild populations migrate over 2,400 miles from their breeding grounds in the wetlands of Wood Buffalo National Park in northern Canada to Aransas National Wildlife Refuge in Texas. According to the *US Fish and Wildlife Service News,* birds arrive to the Aransas National Wildlife Refuge wintering grounds by mid-December and are being monitored. A relatively low proportion of potential crane wintering habitat is protected on federal or state lands, with most habitat found on private lands. This illustrates the main issue of habitat protection for this species, and the need for rigorous but flexible management programs that include partnerships between government agencies, non-governmental agencies, businesses, and private citizens.

Another critically endangered bird is the Attwater prairie chicken (*Tympanuchus cupido attwateri*), for which the US Fish and Wildlife Service has led the breeding and restoration program in partnership with the Houston Zoo and NASA Johnson Space Center. Captive-reared chicks have been released into a protected habitat at the Attwater Prairie Chicken National Wildlife Refuge and are monitored. According to the latest reports, Hurricane Harvey significantly decreased the resident population. However, there was hope that the 49 birds that were released in late fall 2017 would successfully reestablish the breeding population. In the cases of the whooping crane and Attwater prairie chicken, enormous effort has been directed to saving these endangered species. However, the number of bird species joining the ranks of threatened and endangered species continues to rise and will likely accelerate as climate- and weather- related events, coupled with anthropogenic factors impact habitat and adversely affect health, fitness, and longevity of the birds residing there.

1.3.8.6 Unique Characteristics of Birds and Their Role as Sentinels of "One Health"

Diverse life history strategies, and unique physiological and endocrine characteristics differentiate birds from mammals and other vertebrate classes and make them important sentinel species for monitoring environmental health. Birds reproductive strategies fall into two general categories: altricial and precocial. Altricial species include songbirds, which are helpless when hatched and require parental care until they fledge. Most waterfowl, wildfowl, and shorebirds are precocial species, with chicks that are well developed and mobile when they hatch, can feed and forage on their own, but need some parental care, especially protection. Sexual differentiation of reproductive function and the song system occur pre- and posthatch in altricial species (Adkins-Regan et al., 1990), whereas precocial chicks complete sexual differentiation prehatch. Evidence for differential risk to altricial and precocial birds from environmental chemical exposure is increasing, with precocial birds primarily impacted by exposure during embryonic development and altricial birds remaining more vulnerable throughout their lives. However, exposure to environmental chemicals, especially to endocrine disrupting chemicals *in ovo*, can be extremely damaging to individuals from both groups (Ottinger and Dean 2011). As in mammals, sexual differentiation of reproductive and metabolic endocrine function occurs in the embryo and posthatch stages of development and relies on exposure to gonadal steroids. However, in birds, males are the homogametic sex (ZZ) and females are heterogametic sex (ZW).

Birds also have unique physiological and endocrine characteristics that allow them to migrate great distances and survive under extremely variable and sometimes extreme conditions (Gill 1995; Ricklefs 2010). Birds have a higher metabolic rate and body temperature (105 °F) than mammals, both of which may result in accelerated toxicokinetics when exposed to environmental contaminants. Birds that are apex predators, such as osprey (*Pandion haliaetus*), may ingest and feed their chicks prey containing environmental contaminants (Lazarus et al., 2016) resulting in bioaccumulation and biomagnification.

Further, lipophilic compounds (i.e., those stored in fat cells), which include many environmental contaminants, become part of an individual's body burden and may pose a high risk in migratory birds during periods of rapid accumulation (i.e., increased food intakebefore migration) and migration-associated energy drain and mobilization of lipid stores. Thyroid hormone is critical for premigratory fattening and is impacted by exposure to polychlorinated biphenyls (PCBs) and other chemicals that affect the thyroid hormone system (Ottinger and Dean 2011). These rapid shifts in metabolic processes make migratory birds excellent models for understanding the potentially detrimental effects of environmental stressors, contaminants, and disease on human and ecosystem health.

Though it would be predicted that their high body temperature and metabolic rate would result in a shorter lifespan, many birds, including hummingbirds, parrots, and seabirds, exhibit remarkably long lifespans (Ottinger et al. 1995; Nisbet et al. 1999; Holmes and Ottinger 2006; Ottinger and Lavoie 2007). This longevity lends itself to comparisons with human longevity and potential effects of environmental stressors. Typically, long-lived birds have adaptions such as apparent resistance to oxidative damage (Ogburn et al., 2001). Long-lived birds usually don't breed until later in life, unlike short-lived species, and generally produce relatively few (1–2) chicks per year. As such, exposure to environmental contaminants that promote oxidative damage may have adverse effects even in long-lived birds, because the increased damage would weaken overall health and potentially shorten lifespan. Because these birds produce a relatively low number of chicks annually, impaired reproduction and attenuated lifespan have the potential for long-term risk to the population.

1.3.8.7 Ecosystem Restoration and Risk of Adverse Effects from Chemical Exposure

Ecosystem restoration along the Gulf Coast demands accountability for the effectiveness of restoration methods. A primary goal of restoration is more resilient wildlife populations, which can be indicated by increased survival rates and reproductive success. Long-term monitoring of these life history variables is time- and cost-intensive and often provides endpoints without identifying the processes that caused the result, particularly in cases where population recovery is poor. Consequently, few restoration efforts can be reliably assessed, which limits our ability to improve restoration methods. Use of metrics related to physiological health can take less time and often cost less than long-term monitoring while providing a better assessment of the status of a population. Yet for birds, little is known about which health metrics are most appropriate, informative, cost-effective, and convenient for practitioners to assess. Identifying ecologically-important avian health parameters using both large-scale retrospective and fine-scale, species-level approaches are needed. Given the unique characteristics of birds, it is critical to define pertinent metrics to assess the health of individuals and potential risk to populations. Potential overall measures are listed below to provide a general assessment of individual health and fitness.

- Survival and lifespan
- Reproduction and/or viability of young
- Growth rate (important for survival after fledging [Maness and Anderson 2013])
- Health (blood measures, lesions, feather and body condition, parasite load)
- Reproductive axis and other physiological mechanisms
- Neuroendocrine and molecular endocrine regulators

- Behavior (reproductive, stress, health indicators)
- Gonadal steroids, stress hormones
- Immune function and oxidative damage
- Physiological function (thyroid, adrenal)
- Neuroendocrine and/or regulatory status
- Organ systems and pathology

Recent publications provide more specific information on the adverse impacts of exposure to the oil released from the DWH oil spill. Studies of laughing gulls (*Leucophaeus atricilla*) and double-crested cormorants (*Phalacocorx auritus*) showed increased oxidative damage and deleterious effects on cardiac tissue and mortality of some birds (Horak et al. 2017; Pritsos et al. 2017; Harr et al., 2017). Homing pigeons (*Columba livia domestica*) showed altered flight paths after light oiling, suggesting impaired navigational capabilities and flight ability (Pérez et al. 2017). Western sandpipers (*Calidris mauri*) exposed to dietary oil showed reduced blood- and liver-related responses and histological indicators of a stress-related adrenal response (Bursian et al. 2017). Furthermore, there were behavioral impacts on takeoff and flight maintenance in western sandpipers following exposure to small amounts of external oiling (Maggini et al. 2017).

1.3.8.8 Summary

Habitat for birds that reside in or migrate through the GOM is decreasing due to industry, port and trade expansion, and urbanization. It is critical to protect the breeding and wintering grounds of these birds as the effects of climate change progress. Moreover, extreme weather events exacerbate the challenges faced by birds, especially those dependent on finding sufficient food resources to refuel during their migration. In addition to these challenges, there is growing concern for the effects of environmental contaminants and their potential adverse effects on birds, particularly those that are lethal to a subset of individuals or that more widely impair reproductive or metabolic endocrine function and/or depress immune function. It is critical to have reliable assessment tools so that managers can accurately evaluate risk to individuals and populations. Moreover, birds have unique characteristics that make them useful sentinels of ecosystem health. They are indicators of the health of the environment and, because of the close interrelationship with human coastal communities, they provide awareness and understanding of the status of One Health for the GOM.

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2 PART II: THE GULF OF MEXICO–WORKSHOP ON INTERNATIONAL RESEARCH INVENTORY and WORKING GROUP CONTRIBUTIONS

2.1 Introduction

The Gulf of Mexico–Workshop on International Research (GOMWIR) focused on identifying data gaps and research needs in the southern Gulf of Mexico (SGOM) using the GOMWIR Inventory as a point of departure. The workshop and associated working groups also provided a venue to foster collegiality and collaboration among researchers in the countries that share the GOM: the United States, Mexico, and Cuba. This is especially important from the standpoint of managing ocean energy exploration and exploitation throughout the GOM LME since activities in one part of the Gulf can and do affect ecosystems and processes in other parts of the Gulf. As energy exploration, development, and exploitation continues to increase throughout the Gulf, collaboration and cooperation will become increasingly important.

The workshop, working groups, and inventory were organized around three thematic areas defined by BOEM:

- Baseline Studies generate data that describe existing conditions and define a starting point to monitor trends of potentially impacted resources and civil society.
- Fates and Effects Studies evaluate the physical-chemical and biological processes that affect or are affected by the impacts of oil and gas drilling and production discharges, spilled oil, and oil dispersants on biological communities and the societal impacts on potentially affected civil society.
- Environmental Monitoring Studies generate data to assess effects of industry activities and to determine effectiveness of mitigation measures contained within stipulations and conditions of permit approval for activities for offshore energy leases.

Scientists from the around the Gulf with knowledge and expertise in various disciplines within these thematic areas were brought together for the workshop, with 25–50 assigned to each thematic area (Appendix 1). Each participant had one or more of the following attributes:

- International research experience in Mexico and the GOM
- Experience or expertise in nearshore systems of the GOM
- Experience or expertise in deepwater systems of the GOM
- Experience or expertise in socioeconomic aspects of the GOM
- Particular knowledge of experience in one or more of the thematic areas

The plenary sessions were designed to provide all participants with a common, working knowledge of the inventory and research throughout the GOM (detailed in papers contributed by plenary speakers and participants in Part I). Once the plenary sessions concluded, participants joined their assigned working group. The objectives of the working groups were to:

- Contribute to the inventory
- Identify data gaps
- Identify research needs
- Prioritize research questions

2.2 The GOMWIR Inventory

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2.2.1 Introduction and Background

The US Department of the Interior Bureau of Ocean Energy Management (BOEM) has a long-standing research program on marine ecosystem science with relevance to energy management for the northern GOM, and the information is extensive and widely available. Recognizing the need to understand the Gulf as a single LME instead of just regional seas marked by political boundaries, one of the main objectives of the first GOM Workshop on International Research (GOMWIR) was to gather similar information about the state of marine ecosystem science for the SGOM. One specific GOMWIR goal to support this objective (see 1.1 Preface and 1.2.1 Introduction by Larry McKinney in this volume for further details about GOMWIR goals) was to develop an inventory of existing marine ecosystem science for the southern portion of the Gulf. This exploratory effort, the GOMWIR Inventory, would serve as a foundational document for the workshop to provide an initial assessment of the science, which in turn would help identify gaps in knowledge, and inform discussions and planning during the workshop, and into the future. This paper provides information about the considerations that guided the development of the Inventory, some of the technical details behind the effort, and an analysis and discussion of the results that were gathered, and the process in general.

2.2.1.1 Guidance for the Development of the GOMWIR Inventory

The GOMWIR Inventory was conceived as a comprehensive, cross-disciplinary inventory of LME research that would include:

1. An annotated bibliography of peer-reviewed literature, reports and other publications,
2. An annotated listing of Mexican research programs, and
3. An annotated listing of Mexican data sources.

Each of these annotated resources would address one or more of the three BOEM thematic areas of interest, i.e. Baseline Studies, Fates and Effects Studies, or Environmental Monitoring Studies (see 1.2.1 Introduction, this volume), and be focused on the waters of the SGOM. “Annotated” in this context meant including key words, geographic locations, key variables measured or described, and electronic resource locators (URLs, DOIs, etc.), as available.

Though no particular format for these annotated materials was required, a design goal for the GOMWIR Inventory was that it should match the structure of the preexisting BOEM EcoSpatial Information Database (ESID, or “ee-sid”) web application as much as possible. The ESID was a web-based database that stored full-text marine ecosystem literature and data sets in support of BOEM’s National Environmental Policy Act (NEPA) requirements (Madsen et al. 2014). In addition to regular text searches, it had an easy-to-use mapping interface for visual/geospatial searching. The system used PostgreSQLas a backend database and had comprehensive schema with the main resource table composed of approximately 40 metadata fields per bibliographic record (some mandatory, some optional). The ESID was already populated with several thousand records from the United States Atlantic and Gulf Coasts in areas under BOEM’s purview. Thus, the aspiration for matching the ESID structure was that the GOMWIR Inventory could eventually serve as a pluggable data module for the ESID, but with data for the SGOM.

Several important realities also guided development of the GOMWIR Inventory, and especially the design goal of matching the preexisting BOEM ESID structure:

1. Time frame: Very little time was available to actually develop the Inventory between the project start date (September 2016) and the actual Workshop event (March 2017). This time frame also squarely included the end-of-year holiday season with extended break time in both the United States and Mexico. No preexisting solution was available—simply the ESID database schema. Thus, we were charged with developing and implementing an international data collection effort with colleagues from the ground up.
2. Distributed effort: The Harte Research Institute (HRI) and Center for Coastal Studies at Texas A&M University—Corpus Christi (TAMUCC) had a significant amount of knowledge about certain elements of SGOM ecosystem science and databases from extensive work in the past, much of it related to the efforts and research of Dr. J. “Wes” Tunnell. But it was also clear that we were missing many resources of Mexican origin that were not necessarily indexed in international databases, nor directly available to us. Therefore, it was absolutely essential to coordinate the data gathering efforts with Mexican colleagues who either did have direct access to material of interest, or at least knew of its existence.
3. Rigorous nature of ESID records: As mentioned above, the ESID had a comprehensive database schema with approximately 40 metadata fields per bibliographic record. This comprehensive documentation was necessary given that the ESID’s purpose was to support BOEM’s NEPA requirements. Beyond the comprehensive metadata, every ESID record required an OCR’d or digital-born PDF copy of the reference being cited (personal communication, J. Blythe, BOEM Environmental Studies Program, Scientific Data Manager), which was an impossibility for GOMWIR Inventory given the time frame and distributed effort realities mentioned above. Thus, the goal for the GOMWIR Inventory was to match the ESID’s metadata fields as completely as possible.

2.2.2 Methods

Efforts to gather and populate the GOMWIR Inventory with information about bibliographic materials, research programs, and data sources focused on the SGOM occurred both locally, and via critical partnering with a team of Mexican colleagues. At TAMUCC, the efforts were undertaken with the assistance of Justine Thomas (Research Assistant). The Mexican colleagues with whom we partnered had a wide range of expertise and experience in the SGOM. These international colleagues included Dr.
Adolfo Gracia Gasca and León Felipe González Morales of UNAM (Mexico City), Dr. Victor Manuel Vidal Martínez and Daniel Aguirre Ayala of CINVESTAV (Mérida, Yucatán), Dr. Sharon Herzka and Mónica Cecilia Mozqueda Torres of CICESE (Ensenada, Baja California), and Dr. Eustorgio Meza Conde and Sergio Gabriel Jiménez of UAT (Tampico, Tamaulipas). We also established a basic anchor website for information, and widely announced the workshop itself along with a call for volunteer data contributions via mailing lists, presentations, and by personal requests to appropriately connected colleagues who could widen the circles of distribution.

Given the realities that guided the development of the GOMWIR Inventory as discussed earlier, it was decided that a mechanism for data collection using web-based electronic forms would provide the best compromise instead of e-mail document exchanges between multiple parties. We developed a solution using Google Apps Script (GAS) to produce stand-alone, web-based data entry forms that would collect data into a backend Google Sheets spreadsheet. We used this GAS solution because it was readily available to us, benefitted from Google’s resilient infrastructure, and also allowed scientists with different technical skill levels to deal with the data in a familiar form (i.e., either a simple web form or spreadsheet).

An AJAX-based mechanism (Asynchronous JavaScript and XML) was used to submit data from the forms into the spreadsheet, but also preserve the form's content for reuse or resubmission instead of having to reenter a very comprehensive set of metadata from scratch. There was a two-fold rationale behind this decision. First, we suspected that many data contributions by a single person would be related; for example, different chapters from the same book, or papers by the same series of authors, or with the same focus, key words, geographic footprint, etc. At the same time, we also anticipated possibly receiving contributions from other areas like Cuba, where Internet connectivity is often patchy or problematic. The AJAX-based mechanism, by preserving form contents between submission attempts—whether they are successful or not—would allow contributors to either reuse or resubmit a form with an intact set of comprehensive metadata instead of ending up with a blank form and having to laboriously reenter all the extensive data from scratch.

Collected data were first inspected for duplicate records, and then cleaned and prepared by a mix of semiautomated and manual editing methods. Cleaning and preparation was not needed for fields with a controlled vocabulary, i.e. fields represented by check boxes or radio buttons on the web forms, but it was necessary for any free text entry field. This cleaning and preparation did not focus on content, but simply considered the mechanical and formatting aspects of the contributed data. For example, many data were apparently entered by copying and pasting text directly between PDF documents and the web forms. This resulted in errant line breaks, gibberish or extraneous characters, and other odd defects. As the same time, certain fields were reformatted to a specific and consistent convention instead of the freeform styles that were received (for example, all author names were reformatted into "Lastname, Initials of first name" format).

After data cleaning and preparation, an attempt was made to standardize the content of the geographic footprint metadata field. Whereas ESID geographic footprints included both textual descriptions and GIS polygons delineating the geospatial extent of study areas, the realities of the GOMWIR Inventory data collection effort only allowed for textual descriptions. These textual descriptions were provided in a variety of formats including as geographic coordinates, physiographic or bathymetric descriptions, political descriptions, and were also mixed between Spanish and English. Thus, this metadata field was split into three separate subfields and standardized formats to facilitate both plotting onto maps, and text- based searches.

A simplified subset of data (just seven fields) was extracted for presentation at the GOMWIR event in March 2017. Data were presented to the workshop participants in simple list form for the three breakout sessions, and also plotted on three large maps (80" x 48", ~2 m x ~1.2 m) for visualization. The maps also served as the basis for a live, on-the-fly data gap analysis exercise during the workshop. For this exercise, workshop participants were provided with small stickers with personally-identifying numbers to link the stickers back to them. Participants who knew of other SGOM resources that had not yet been identified and included in the GOMWIR Inventory could affix their stickers to the maps so they could be contacted after the workshop to provide further details about the particular resources that were missing from the Inventory. Following the workshop, the location of each of these stickers on the three maps was digitized and linked back to the participants who were individually solicited by e-mail to provide further details about the data and resources missing from the Inventory.

2.2.3 Results

After duplicate record removal, the GOMWIR Inventory ended up capturing 897 bibliographic references, 33 records about research programs, and five records about data sources. The bibliographic records were almost exclusively entered into the Inventory via the web forms either under our own local effort (~68% of total records), or by the international participants (~32% of total records) with whom we had partnered, i.e., there were only two volunteer contributions of data, despite our advertising efforts. The totals above only include information that was submitted via the web forms as data was suitably parsed into specific metadata fields, and generally complete enough to be useful. In turn, in several instances, typical bibliographic/publication lists were supplied, but these lists do not provide the comprehensive metadata that is needed to make the information immediately actionable for inclusion into the GOMWIR Inventory. For example, such bibliographic and/or publication lists are missing basic metadata characteristics like categorization by one of the three main BOEM thematic areas, eight resource categories, key words, or geographic footprint covered by the resource. The bibliographic references provided via these lists are being assessed as time permits, and if it is possible to fill in basic metadata gaps, these resources will be included in future revisions of the Inventory.

The actual GOMWIR Inventory in spreadsheet format is provided as a special electronic addendum to this document. The intended final format of the Inventory is not a spreadsheet, and this is further discussed in the Discussion/Analysis section of this document.

In the following paragraphs, summarized results from the GOMWIR Inventory collection effort are provided using simple percentage statistics. To facilitate summarizing the bibliographic references, which were contributed in large numbers, the bibliographic references are split into three subsets by BOEM thematic area. In turn, the smaller number of records received about research programs and data sources means that no splitting is necessary.

2.2.3.1 Bibliographic Contributions by Baseline Studies Thematic Area

The vast majority of annotated bibliographic contributions fell under the Baseline Studies thematic area (571 out of 897 total records, or ~64%; see Figure 45 for map of locations). In comparison, the Fates and Effects Studies thematic area was flagged for just ~19% of the records, and the Environmental Monitoring Studies thematic area for ~28% of the records. It is noted that references could be flagged for more than one of the thematic areas; thus, the percentages sum to greater than 100%.

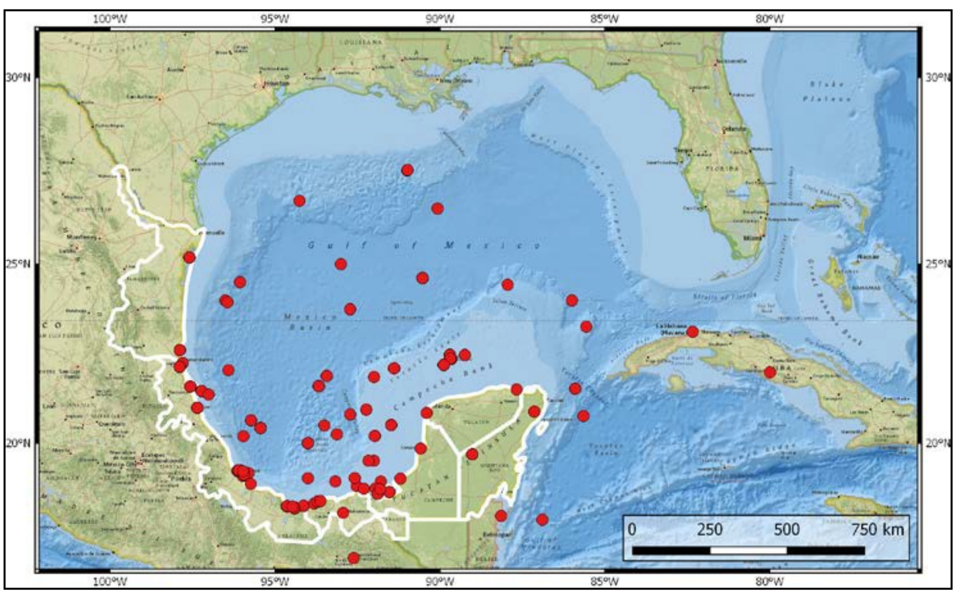

Figure 45. Locations of baseline studies in bibliographic records.

Note that the scale of this map, and the fact that many records share common geographic place names or coordinates (see Discussion section) precludes showing all 571 points separately. Most red dots on the map actually represent multiple bibliographic records from the Inventory. Basemap from Esri Basemap layers collection.

With regard to the eight possible resource categories for Baseline Studies contributions, “Pelagic ecology” (~36%) was the most commonly indicated category followed by “Infauna/Meiofauna” at ~29% (Figure 46, panel A). “Water quality” and “Coral and Hardbottom” were the next most commonly indicated categories at ~17% and ~16%, respectively. Finally, “Physical processes,” “Geology,” and “Demersal fish” all hovered around the 10% mark, while “Seagrass” was only indicated for ~6% of the contributions.

“Journal article” was the most common (~40%) type of bibliographic resource documented in the Inventory followed by “Dissertation/Thesis” at ~20% and “Abstract” at ~17% (Figure 46, panel B). In decreasing order from ~8% down to ~1%, other resource types were specified as “Conference Proceedings,” “Book, Section/Chapter,” “Report,” “Book, Whole,” and “Other.” Only one “Map” and zero “Web Page”-types were indicated for records in the Inventory.

The bulk of reported Baseline Studies bibliographic contributions are from the 1980s (~30%) and 1990s (~24%) (Figure 46, panel C). Contributions from each of the two decades prior (1960s and 1970s), and each of the two subsequent decades (2000s and 2010–present), also each account for about ~10% of the inventory. Very little (~3%) of the literature is from before the 1960s.

With respect to geographic distribution by Mexican (MX) state, the vast majority (~49%) of contributed literature records are associated with Veracruz, with the state of Yucatán being the next most commonly indicated at ~12% (Figure 46, panel D). Very little of the literature is linked to Tamaulipas or Campeche, just ~6% and ~8%, respectfully. Tabasco and Quintana Roo are hardly represented at ~2% apiece. On a related note about geographic footprints, a simple frequency analysis of the ten most commonly indicated geographic place names for records in the Baseline Studies thematic area is provided in Table 4.

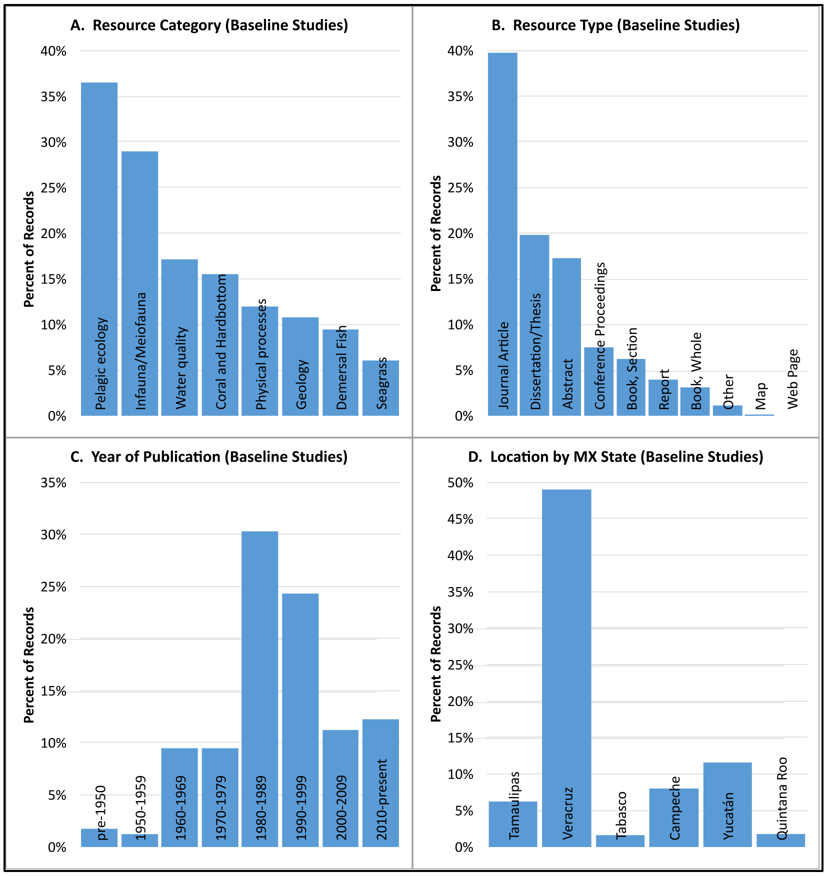

Figure 46. Simple percentage statistics for Baseline Studies bibliographic records.

Table 4. Top 10 geographic place names indicated for Baseline Studies bibliographic contributions

Name	Counts
Laguna de Tamiahua	99
Laguna de Tampamachoco	67
Gulf of Mexico	46
Laguna Pueblo Viejo	29
Laguna Madre	25
Alacrán Reef	20
Southern Gulf of Mexico	18
Campeche Bank/Yucatán Shelf	17
Veracruz	16
Enmedio Reef	12

2.2.3.2 Bibliographic Contributions by Fates and Effects Studies Thematic Area

The GOMWIR Inventory ended up with 166 records (~19% of 897 total records; see Figure 47 for map of locations) of bibliographic resources that were linked to the Fates and Effects Studies thematic area.“Water quality” was the most commonly indicated category (~47%) for these records followed by “Infauna/Meiofauna,” “Physical processes,” and “Pelagic ecology” at ~40%, ~34%, and ~25%, respectively (Figure 48, panel A). The “Coral and Hardbottom,” “Demersal Fish,” and “Seagrass” categories each accounted for about 10% of the records, while “Geology” was the least-mentioned category at 7%.Most of the records for Fates and Effects Studies bibliographic contributions were of type “Journal Article” (~45%) while ~23% of the records were linked to “Dissertation/Thesis”-type resources, and~13% to typical “Reports” (Figure 48, panel B). Regarding “Conference Proceedings,” “Book, Whole,” “Abstract,” and “Book, Section/Chapter”-types, each of these accounted for ~5% each of the total Fates and Effects Studies bibliographic contributions. No “Map,” “Other,” or “Web Page”-types were indicated for any of the Fates and Effects Studies records.

The publication year results for Fates and Effects Studies bibliographic contributions is interesting (Figure 48, panel C). There are no records present that are from prior to the 1960s, then just ~1% in the 1960s, and ~4% in the 1970s. However, by the 1980s and 1990s, the quantity of southern Gulf Fates and Effects Studies literature increases tremendously, and these decades account for ~19% and ~22%, respectively, for literature records in this thematic area. The amount continues to expand moving forward in time, and some 28% of the Fates and Effects Studies literature captured by the GOMWIR Inventory was produced during the 2000’s. Finally, in the eight years since that point, i.e., 2010–2017, ~27% of the literature can be linked to this decade.

Similar to the Baseline Studies literature records, Veracruz is the most commonly indicated Mexican state for Fates and Effects Studies literature at ~26% (Figure 48, panel D). Campeche State has the next most abundant focus at ~15% with Tabasco indicated slightly less frequently for ~12% of the Fates and Effects Studies records. Yucatán was the geographic focus of ~8% of the bibliographic contributions from this category whereas there was little literature associated with Tamaulipas (~2%); there are no records for this category from Quintana Roo. A simple frequency analysis of the ten most commonly indicated geographic place names for Fates and Effects-focused literature is provided in Table 5.

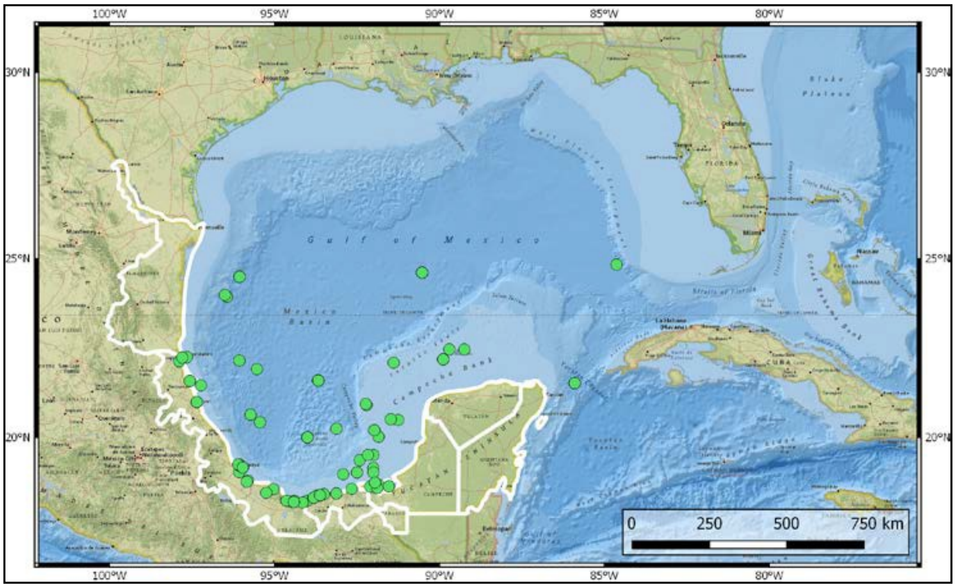

Figure 47. Locations of Fates and Effects Studies in bibliographic records.

Note that the scale of this map, and the fact that many records share common geographic place names or coordinates (see Discussion section) precludes showing all 166 points separately. Most green dots on the map actually represent multiple bibliographic records from the Inventory. Basemap from Esri Basemap layers collection.

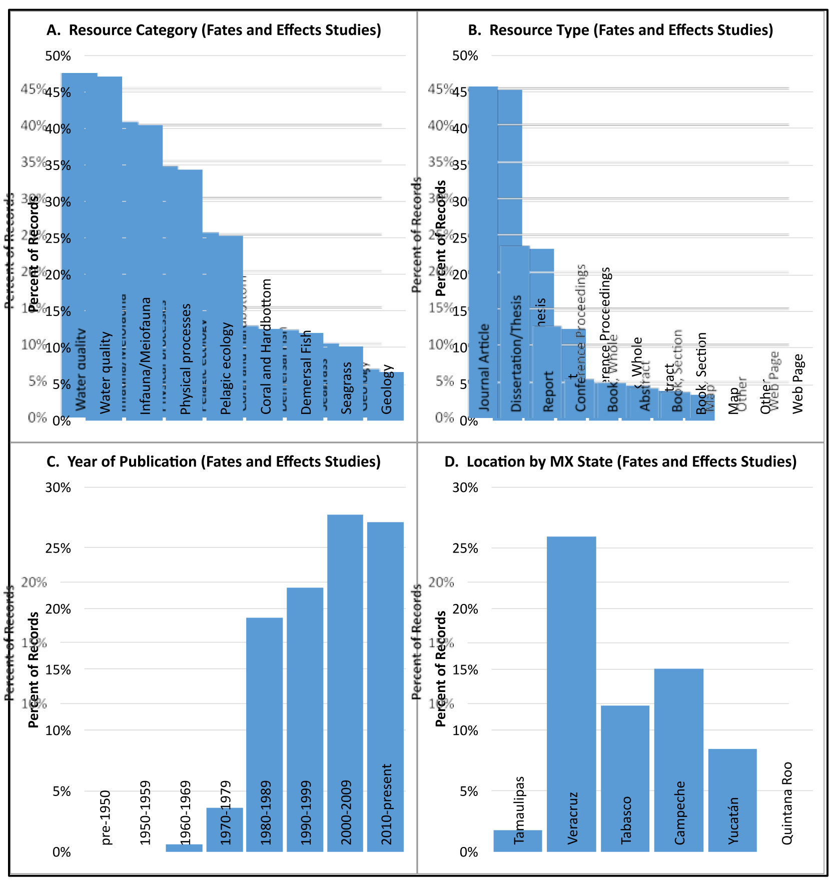

Figure 48. Simple percentage statistics for Fates and Effects Studies bibliographic records.

Table 5. Top 10 geographic place names Indicated for Fates and Effects studies bibliographic contributions

Name	Counts
Gulf of Mexico	30
Southern Gulf of Mexico	13
Loop Current (Yucatán Channel)	8
Laguna de Tamiahua	6
Laguna de Tampamachoco	6
Sonda de Campeche	6
Veracruz Reef System	6
Bay of Campeche	5
Campeche Bank/Yucatán Shelf	4
Coatzacoalcos	3

2.2.3.3 Bibliographic Contributions by Environmental Monitoring Studies Thematic Area

The GOMWIR Inventory ended up with 250 records (~28% of 897 total records; see Figure 49 for map of locations) of bibliographic resources that were linked to the Environmental Monitoring Studies thematic area.

With respect to resource category, "Water quality" and "Pelagic ecology" together account for almost 75% of the Environmental Monitoring Studies literature at ~41% and ~33%, respectively (Figure 50, panel A). The "Infauna/Meiofauna" resource category is also well-represented with ~28% of the contributed literature records. "Coral and Hardbottom," "Physical processes," and "Demersal fish," are indicated for ~16%, ~14%, and ~13% of bibliographic records. Finally, the "Seagrass" and "Geology" categories are the least commonly designated categories at just ~10% and ~7%, respectively.

The distribution of bibliographic resource types for literature in the Environmental Monitoring Studies thematic area is relatively distinct from the two other thematic areas. The "Journal Article"-type of resource is still the most common type at some ~27%, but the "Abstract"-type is the second most abundant at ~24% (Figure 50, panel B). "Dissertation/Thesis," "Conference Proceedings," and "Report"- types are indicated in approximately the same magnitude at ~13%, ~11%, and ~11%, respectively. Environmental Monitoring Studies literature designated as the "Book, Section/Chapter"-type accounts for ~6% of the records, while the remaining "Book, Whole," "Other," and "Web Page"-types all contribute less than 5% of records in this thematic area. Finally, as was the case for the other two thematic areas, there are no "Map"-type records registered in the Inventory.

Regarding the year of publication for bibliographic records in this thematic area, there are clear peaks in the decades of the 1980s (~28%) and the 1990s (~31%) (Figure 50, panel C). The earliest records in this Inventory thematic area are from the decade of the 1960s (~4%) and the 1970s (~6%). The 2000s and period from 2010 to present account for ~19% and ~11%, of the records.

With respect to the distribution of Mexican states designated for the bibliographic records in this thematic area, Veracruz is again the most commonly specified state at ~52% (Figure 50, panel D). Tamaulipas is the second-most represented state at ~9% of the records, whereas the states of Campeche and Yucatán each account for ~6% of the contributed records in the Environmental Monitoring Studies thematic area. The states of Tabasco and Quintana Roo are poorly represented at ~3% and ~1%, respectively. A simple frequency analysis of the ten most commonly indicated geographic place names for Environmental Monitoring literature is provided in Table 6.

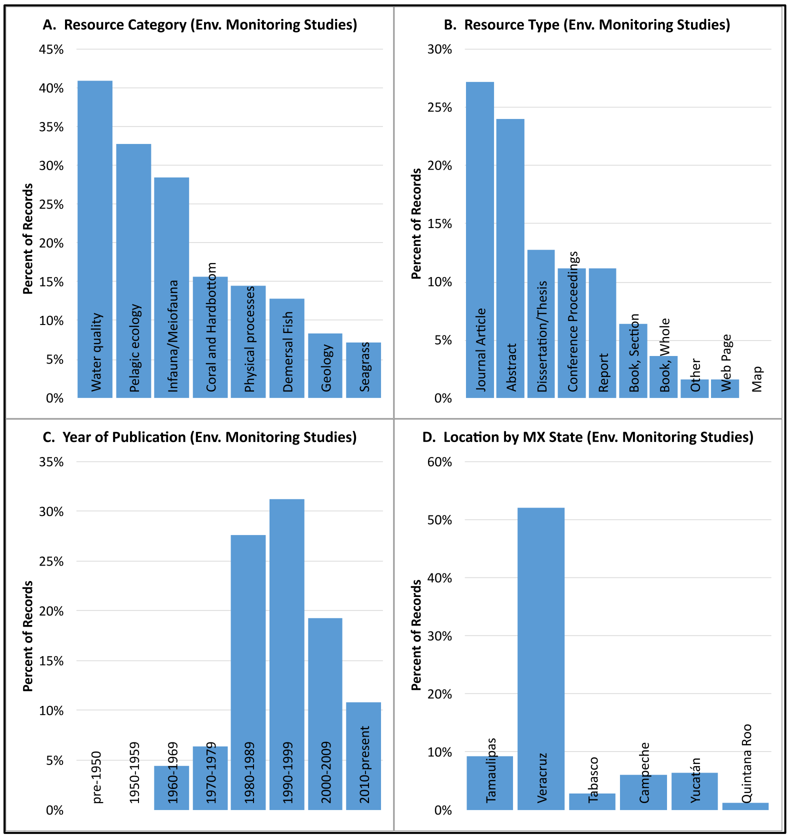

Figure 49. Simple percentage statistics for Environmental Monitoring Studies bibliographic records.

Table 6. Top 10 geographic place names Indicated for Environmental Monitoring studies bibliographic contributions

Name	Counts
Laguna de Tamiahua	44
Laguna de Tampamachoco	36
Gulf of Mexico	19
Laguna Madre	19
Southern Gulf of Mexico	13
Veracruz Reef System	10
Alacrán Reef	8
Port of Veracruz	8
Laguna Pueblo Viejo	6
Campeche Bank/Yucatán Shelf	5

2.2.3.4 Inventory Results for Research Programs Focused on the Southern Gulf of Mexico

Data collection efforts for the GOMWIR Inventory captured 33 records about research programs focused on marine ecosystem science and related themes in the SGOM. The vast majority of research programs (28 out of 33) were classified as academic in nature, being the product of a university or an academic research organization. A small quantity (just four out of 33) was classified as governmental in nature, being a product of the government or a government agency, such as the Mexican Ministry of the Navy, the Ministry of Environment and Natural Resources, or similar. Finally, information about a single research program that was the product of a nongovernmental organization was also provided to the Inventory effort.

With respect to the organizational scope of these research programs, nine were identified as being broadly organized at the level of a consortium, collaboration, or working group of researchers at multiple organizations, institutions, or agencies. Another 12 of the research programs were mid-tier in size and identified as a collaboration or working group within a single organization, institution, or agency, such as multiple departments within the same organization. Finally, the remaining 12 research program contributions involved a working group at the departmental or lab level, including multiple researchers in the same department, a faculty member directing student research, or similar.

2.2.3.5 Inventory Results for Data Resources Focused on the Southern Gulf of Mexico

The GOMWIR Inventory data collection process received information about five data sources with marine ecosystem science content and related themes in the SGOM. These include:

1. CONABIO Integrated Publishing Toolkit for Biodiversity Data
2. CONACYT-SENER Hydrocarbon Fund Project 20144 (restricted availability, no URL provided)
3. IUCN Red List of Threatened Species
4. Florida Fish and Wildlife Conservation Commission Open Data System
5. REEF Volunteer Fish Survey Project

Data sources 1 and 2 were identified as academic, 3 and 4 as governmental, and 5 as nongovernmental, using the same definitions of these entities in the preceding section focused on Research Programs. All five data sources house biological data. Two of the data resources maintain additional datasets with one also housing oceanographic, water column, and chemical datasets (source 2), while the other includes oceanographic and geospatial data in addition to biological data (source 4). Three of the data sources supposedly allow remote electronic access to data with no mention of restrictions (sources 3, 4 and 5). Two of the data sources (1 and 2) provide data with restricted availability, in which the data resource is not private, but has some restriction for access like payment, membership in a certain organization, or some other factor.

2.2.3.6 Results in Sticker-Based Data Gap Analysis and Follow-Up

The live, on-the-fly, data gap analysis exercise using stickers on the three large BOEM thematic area maps finished with 495 data points being added to the three maps (Figure 51). Workshop participants placed stickers on the maps to indicate locations of known resources (bibliographic resources, data resources, etc.) that were not included in the GOMWIR Inventory presented at the workshop. Some miscommunication caused participants to indicate locations throughout the entire Gulf instead of just focusing on the southern portion, but nonetheless, all contributed sticker data points were maintained.

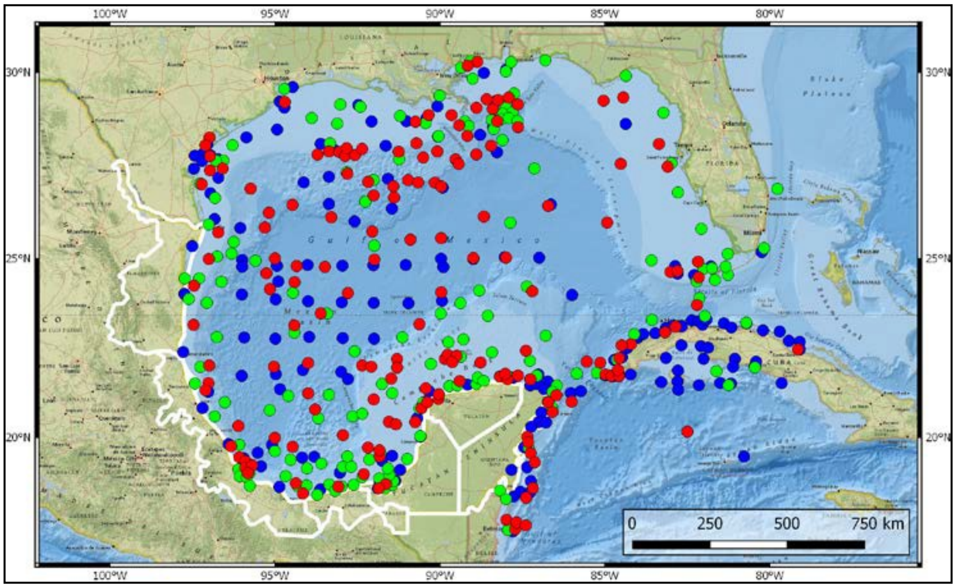

Figure 50. Locations of 495 resources not included in the GOMWIR Inventory but identified by the data gap analysis sticker exercise.

Red dots represent stickers placed on the Baseline Studies map, green dots represent stickers placed on the Fates and Effects Studies map, and blue dots represent stickers placed on the Environmental Monitoring Studies map. Basemap from Esri Basemap layers collection.

There was a very equitable distribution between stickers on the three thematic area maps:

1. The **Baseline Studies** map received 165 out of 495 stickers, or ~33%,
2. The **Fates and Effects Studies** map received 157 out of 495 stickers, or ~32%, and
3. The **Environmental Monitoring Studies** map received 173 out of 495 stickers, or ~35% of the total.

The follow-up attempts to get basic data about these missing resources were, unfortunately, extraordinarily unsuccessful. Despite multiple individual solicitations by e-mail (i.e., no mass broadcast e- mails) to participants that had placed stickers, including a reminder of how many stickers that participant had placed in certain approximate locations, not a single reply was received to help fill in these gaps.

2.2.4 Discussion and Analysis

2.2.4.1 Patterns and Trends in the Bibliographic Data, and Insights about Knowledge Gaps

Because of the small number of contributions about research programs and data resources that were collected for the GOMWIR Inventory, attempting to draw any valid conclusions about marine ecosystem science in the SGOM based on those small datasets does not make sense. However, with the almost 900 bibliographic data records that were collected some observations can be made. We make the assumption that these almost 900 records provide a generally representative sample of the overall population of marine ecosystem science that has actually been undertaken in the SGOM. Some of the results from the Inventory suggest this is the case, but other results suggest these almost 900 records are probably biased for some obvious reasons as explained below.

One simple observation can be drawn about the distribution of records with respect to the three BOEM thematic areas. There were more than twice the number of contributions in the Baseline Studies thematic area (571 out of 897 total records, or ~64%) than in the Environmental Monitoring Studies thematic area (250 out of 897 total records, or ~28%), and more than three times the number of records than in the Fates and Effects Studies thematic area (166 out of 897 records or ~19%). The same general trend was evident in the interests of the researchers who wanted to attend the actual workshop event. Specifically, there were many more people who declared an interest and expertise in Baseline Studies than the other two thematic areas. Given the concordance of these trends, this suggests the almost 900 bibliographic references are indeed representative of the greater population of marine ecosystem science that exists for the region. Furthermore, the distribution between thematic areas is perhaps not too surprising given the long historical tradition of field surveys and exploration that can easily be related to Baseline Studies, and the potentially lower barrier to entry for this type of research depending on details. In turn, Fates and Effects Studies might be interpreted as more specialized and as having a potentially higher barrier to entrance given the need for specialized analytical equipment and methods. Depending on perspective, the overall distribution might suggest that efforts should be made to increase the numbers of Fates and Effects Studies in the future, if they are valued equally or greater than the other thematic areas.

With respect to resource categories, in all three thematic areas, resources focused on “Pelagic ecology,” “Infauna/Meiofauna,” and “Water quality” categories were always well-represented. In turn, resources focused on “Coral and Hardbottom” and “Physical processes” categories were generally represented at intermediate percentages. Finally, for all three thematic areas, resources focused on “Geology,” “Demersal Fish,” and “Seagrass” categories were never particularly well represented. Depending on perspective, this might be seen as a strong suggestion that more efforts should be dedicated to work focused on the least-represented categories of “Geology,” “Demersal Fish,” and “Seagrass.”

Some interesting trends can be seen in the Year of Publication results from the three thematic areas. Both Baseline Studies and Environmental Monitoring Studies show strong peaks in activity during the decades of the 1980s and 1990s with decreases from those earlier peak values over the last two decades. In turn, publications focused on Fates and Effects Studies ramp up slowly, but have a strong, increasing growth over the last four decades, with the numbers of studies peaking in the last two decades. Currently, there is not a good explanation about why this is the case.

Several interesting observations can be made about the geographic footprint results. With respect to qualifications by Mexican states, Veracruz is by far the most well-represented state in all three thematic area groups, with two to five times more representation than any other Mexican state. In turn, Quintana Roo is uniformly the least well-represented in all of the thematic areas. The very strong representation for Veracruz is probably related to the massive amounts of effort that have been dedicated to marine ecosystem science in and around the Veracruz Reef system through the years. In turn, poor representation of Quintana Roo is probably due to the fact that only a small corner of the state actually falls within the SGOM with the majority of the state facing the Caribbean Sea. Likewise, Tamaulipas and Tabasco have received less attention than Campeche and Yucatán, likely also reflecting the focus on coral reefs and the exploitation of oil reserves on Campeche Bank.

The top 10 geographic place names for each thematic area based on frequency analysis suggest that the Inventory has a geographic bias in some cases. For example, certain place names like Laguna de Tamiahua and Laguna de Tampamachoco have bubbled to the top of these frequency analyses, but other well-known places like Laguna de Términos have not. However, there is a clear and straightforward explanation for this. In particular, part of the local effort at TAMUCC involved an attempt at mining the voluminous SGOM literature collection amassed by Wes Tunnell over his career. The collection is organized on a thematic basis, for example, a folder of material is focused on

Laguna de Tamiahua, another on Laguna de Tampamachoco, and so on and so forth. Given the expedited schedule for this exploratory effort, only a subset of these thematic folders was examined within the timeline for this project. The thematic folders for these two lagoons did make it into this exploratory effort, hence, their elevated frequency counts. This bias, therefore, simply results from the short amount of time that was available for developing the Inventory.

Some other observations from these frequency analyses emerge as well, in particular, the existence of place names that indicate very broad, generic areas like "Gulf of Mexico," or "Southern Gulf of Mexico," or "Campeche Bank." These results, together with the map figures, point out one of the weaknesses in the GOMWIR Inventory—the collection of geographic footprints—and this is further explained in the following section.

2.2.4.2 Geographic Footprints—An Opportunity for the Future

Besides the comprehensive textual metadata that composed the main body of each BOEM ESID record, we noted that GIS polygons delineating the geospatial extent of study areas were also included. However, given the realities of the GOMWIR Inventory data collection effort, the collection of GIS polygons for each record could not be accomplished for a couple of reasons.

First, because of the extremely short time frame for collecting the data, the effort was only meant to be exploratory. To define a detailed GIS polygon for any individual study or publication, it is imperative to carefully read the text to find the geographic footprint. In some cases, it is obvious because a publication includes a map indicating the specific region of interest. However, this is not the case for many other publications so a detailed reading is necessary. Also, much of the actual data entry was performed by students who did not have had the necessary skill set or equipment/software to produce GIS polygons. Thus, our geographic footprints were provided as textual descriptions by geographic coordinates, physiographic or bathymetric place names or descriptions, and political descriptions.

A significant issue with collecting only textual information is that if it is not easy to determine a detailed geographic footprint for any particular record, substituting in a broad, generic place name like "Gulf of Mexico" or "Campeche Bank" is often the only solution. Thus, many database records end up sharing the same, broad generic place names for their geographic footprint. This has major detrimental effects on maps that attempt to plot this data. For example, this can be seen with the three BOEM thematic area maps (see Figure 45, Figure 47, and Figure 49). In those maps, it looks like there are very few data points compared to the actual ~900 database records that exist. This is because many of those records were entered into the Inventory with just a broad, generic place name as their geographic footprint, so many records share the exact same data point.

Thus, a future opportunity for expansion of the GOMWIR Inventory, if resources were to become available, would be to include the addition of the geographic footprints for the studies of interest. Such inclusion would provide more specific metadata describing each study, which would improve searching capabilities and gap analyses, by identifying the specific regions of interest for each study.

2.2.4.3 Completeness of the GOMWIR Inventory—Another Opportunity for the Future

At the beginning of the process to develop and populate the GOMWIR Inventory, it was unclear just how many records with complete metadata could be collected in the time allotted especially given its nature as a collaborative, international effort. The nearly 900 bibliographic references that were compiled are a satisfactory start, but the current Inventory just scratches the surface of what is available. For example, beyond these ~900 references, simple bibliographic and publication lists were also collected and received, and they hold hundreds of additional resources that could potentially be added to the Inventory after gathering the supporting metadata. Similarly, Wes Tunnell's SGOM literature collection contains many hundreds more resources that simply could not be added to the Inventory give time constraints. And furthermore, several important, well-known compilation volumes focused on SGOM ecosystem science were only sparsely referenced in the Inventory or simply did not make it at all. A few select volumes in this category include Yáñez-Arancibia and Day (1988), Salazar-Vallejo and González (1993), Caso et al. (2005), Botello et al. (2011) and Sanchez et al. (2012). Just these five example compilations comprise almost 200 publications, which collectively include some 8,600 bibliographic references of potential interest.

Finally, we also note that a vast amount of ecosystem science also exists for the Cuban part of the Gulf, but the Inventory contains almost nothing from Cuba at this point. This unfortunate fact is simply due to the short amount of time that was available for this exploratory effort, and the general lack of good Internet connectivity available on the island. Fortunately, efforts are underway to change this. For example, HRI is currently involved with Cuban colleagues from the Center for Fisheries Research (CIP) in Havana to scan and OCR their historic collection of the *Revista Cubana de Investigaciones Pesqueras* (Cuban Journal of Fisheries Research). This effort involves about 60 physical volumes published between 1975-2006 (later versions are already online) that together comprise about 5,800 journal pages. This effort will unlock a huge amount of historic baseline data for the region, and is just one of many resources focused on Cuban coastal and marine ecosystem science that could be added to the GOMWIR Inventory as time and resources permit.

In sum, the ~900 bibliographic references compiled for the first version of the GOMWIR Inventory represent a satisfactory start given the short time frame and collaborative, international nature of the effort. But a vast amount of additional information is already known about, and could be added to the future revisions of the Inventory.

2.2.4.4 Other Observations and Comments

We have a couple of observations and comments about the GOMWIR Inventory process that, in general, may benefit future efforts.

First, volunteer data contributions were essentially neglible despite the large number of scientists and researchers that we reached with our workshop and inventory announcement messages. This is perhaps understandable given the many generic requests for information that scientists receive on a frequent basis. But even in the case of the follow-up to the map sticker exercise, when we wrote individual, personalized e-mails to participants who indicated via their stickers that they knew about studies or publications that were missing from the Inventory, not a single followup response was received. Thus, efforts to solicit data contributions from scientists were not very effective in this case.

Second, an improved process for contributing geographic footprints with data records is needed. Supposing that only textual contributions for footprints are possible, much stronger guidance about what constitutes a good option—and what will actually be accepted—is recommended. But ideally, a system with simple and easy-to-use geospatial tools (like Google Earth) might allow for direct collection of GIS polygons from volunteer data contributors.

2.2.4.5 Disposition of the GOMWIR Inventory

As discussed at the start of this paper, one of the main design goals during the planning and development stages of the GOMWIR Inventory was to match it with the structure of the database behind the BOEM ESID web application as closely as possible. The aspiration behind this effort was that the GOMWIR Inventory could one day, with sufficient polishing and effort, possibly serve as a pluggable data module for the ESID providing the missing coverage for the SGOM. Unfortunately, while the data collection process for the GOMWIR Inventory was underway, we learned that BOEM had made a strategic decision to stop pursuing the ESID due to increasing costs and IT requirements (personal communication, J. Blythe).

This unexpected change provides some flexibility regarding the final format and disposition of the GOMWIR Inventory. Given the time and effort that were expended to pull it together, and the very nature of the GOMWIR event to encourage trinational cooperation and coordination, the hope is that the Inventory can be made freely available to the greater GOM community. At the very minimum, it could be made available to end users as a simple, static, downloadable data table or GIS data file. But ideally it would be deployed as a web application with similar, but simplified, functionality as the former ESID, especially the easy-to-use mapping interface for visual/geospatial searching. An even better outcome is that the Inventory would not be a static database, but a living database that the community could continue to polish, revise, and extend as needed. However, our experience that voluntary data contributions are generally negligible suggests that our own efforts would probably be more key. Different potential solutions that would meet these goals are currently being investigated as are the necessary time, energy, and financial commitment that the various solutions would entail. Thus, for the moment, we will simply leave the GOMWIR Inventory as extensive, spreadsheet-based data tables until a decision is made.

2.2.5 Summary

The GOMWIR Inventory was developed as a foundational document to support the first Gulf of Mexico Workshop on International Research (GOMWIR). The Inventory was conceived as a comprehensive, cross-disciplinary inventory of LME research that would include:

1. An annotated bibliography of peer-reviewed literature, reports and other publications,
2. An annotated listing of Mexican research programs, and
3. An annotated listing of Mexican data sources.

Each of these annotated resources would address one or more of the three BOEM thematic areas of interest, i.e. Baseline Studies, Fates and Effects Studies, or Environmental Monitoring Studies (see 1.2.1 Introduction, in this volume) and be focused on the waters of the SGOM.

To produce the Inventory, a stand-alone web form system was developed using Google Apps Script to electronically collect data into a backend Google Sheets spreadsheet. A team of local and international partners was assembled to help gather information about resources of interest and enter it into the online web forms. Using this mechanism, 897 bibliographic references, 33 records about research programs, and five records about data sources were captured and entered into the database.

Several geographic trends, research themes, and temporal patterns were recognized in the collected data, and they were used to make loose suggestions about certain priorities for future investigation of marine ecosystem science in the SGOM.

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2.3 Case Study: Using an Inventory to Conduct a Gap Analysis in the Southern Gulf of Mexico

N. Simoes

Unidad Multidisciplinaria de Docencia e Investigación de Sisal (UNAM)

2.3.1 Background

My colleagues at Unidad Multidisciplinaria de Docencia e Investigación de Sisal (UNAM) and I were contracted by the Harte Research Institute of Gulf of Mexico Studies (HRI) to use an inventory to produce a gap analysis of the species diversity from benthic habitats in the southern Gulf of Mexico (SGOM) related specifically to oil and gas exploration and extraction and its associated risks. General information about this project is available at (in Spanish), and a report on the project (English) is on file at HRI. The presentation that I gave during the plenary session of the GOMWIR can be found here.

The gap analysis that was produced from an inventory demonstrates the potential of bibliographic inventories to describe and summarize the state of current knowledge, to help identify new research questions and priorities, and to inform management needs.

The objectives of the Simoes et al. (2016) gap analysis were:

- To describe historic benthic sampling effort in the SGOM
- To compile species occurrence from different sources
- To identify SGOM areas that were poorly sampled and poorly described
- To identify vulnerable areas in the SGOM prone to impact from natural and anthropogenic disturbances, particularly oil and gas development.

Data were compiled on a specific set of animal taxa known to represent at least 80% of the benthic species in the SGOM (fish, cnidarians, sponges, crustaceans, molluscs, annelids, echinoderms, platyhelminths, bryozoans, and tunicates). The species list used to guide the data compliation is largely extant in the book “Gulf of Mexico, Origin, Waters, and Biota, Volume 1: Biodiversity” (Felder and Camp 2009). Diversity, abundance, and distribution data were mined from the Ocean Biogeographic Information System, Mexico’s National Biodiversity Information System from the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), and UNAM’s scientific collections. Taxonomic nomenclature and systematics followed World Registry of Marine Species (WoRMS) and Assembling the Tree of Life (AToL AToL Decapoda).

Parallel to the data mining from online or publicly-available databases, there was an effort to identify the potential for extracting species distribution points from papers in specialized academic journals, as well as other sources, such as reports and theses cited in Felder and Camp (2009). A modified PRISMA statement protocol (Moher et al. 2009) was followed to clearly indicate the sequence of actions and criteria used to extract information from bibliographies to be included in meta-analysis such as this one.

From an initial 2,820 known published sources of information with potential information on taxa, such as fish, cnidarians, sponges, crustaceans, mollusks, echinoderms, bryozoans, and tunicates, only 1,069 were accessible through PDF or print, indicating a clear need to digitize older bibliographies. Books and technical reports by state or federal agencies were information sources which were more difficult to get copies of.

For the historic benthic sampling effort, location information was gathered from a variety of resources, concentrating on those institutions that had or have research vessels: UNAM, PEMEX, NOAA (US Department of Commerce), Secretaría de Marina (SEMAR), and Instituto Nacional de Pesca (INP). A total of 8,077 sampling points were identified.

Information about the geographic distribution of current oil fields (Figure 52) and oil field auction blocks to be explored within the next decades (Figure 53), as well as locations of seismic surveys from 2015 was obtained from Mexico's Comisión Nacional de Hidrocarburos (CNH). The historic paths of Category 4 or 5 hurricanes up to December 2016 were also compiled. Type of coast (e.g., coral reef, rocky shore, etc.) was determined from Atlas de vulnerabilidad ambiental del Golfo de México (UNAM 2006). Geographic information was plotted on a one-tenth and one-fifth degree grid for Mexico's Economic Exclusive Zone (7,572 and 1,946 total pixels, respectively). A rapid spatial analysis was run using a simple summed scale for "oil-spill- risk" (presence of active oil wells and pipelines + recently adjudicated oil fields + 5 year national oil fields bidding program + frequency of seismic surveys + depth + distance to the continental or island coasts + accumulated historic hurricane activity) and species density, to identify those areas where very little knowledge exists on the local fauna, and the risk of an oil spill is large.

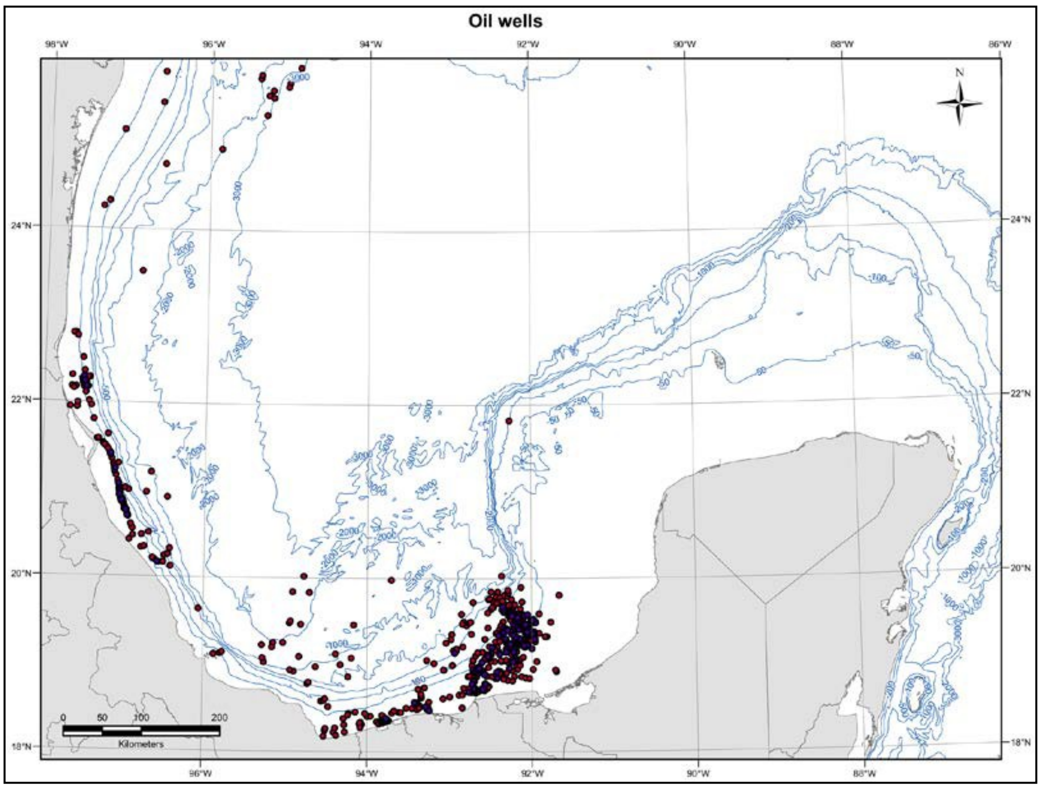

Figure 51. Map of current petroleum production in the SGOM.

From Simoes et al. (2016).

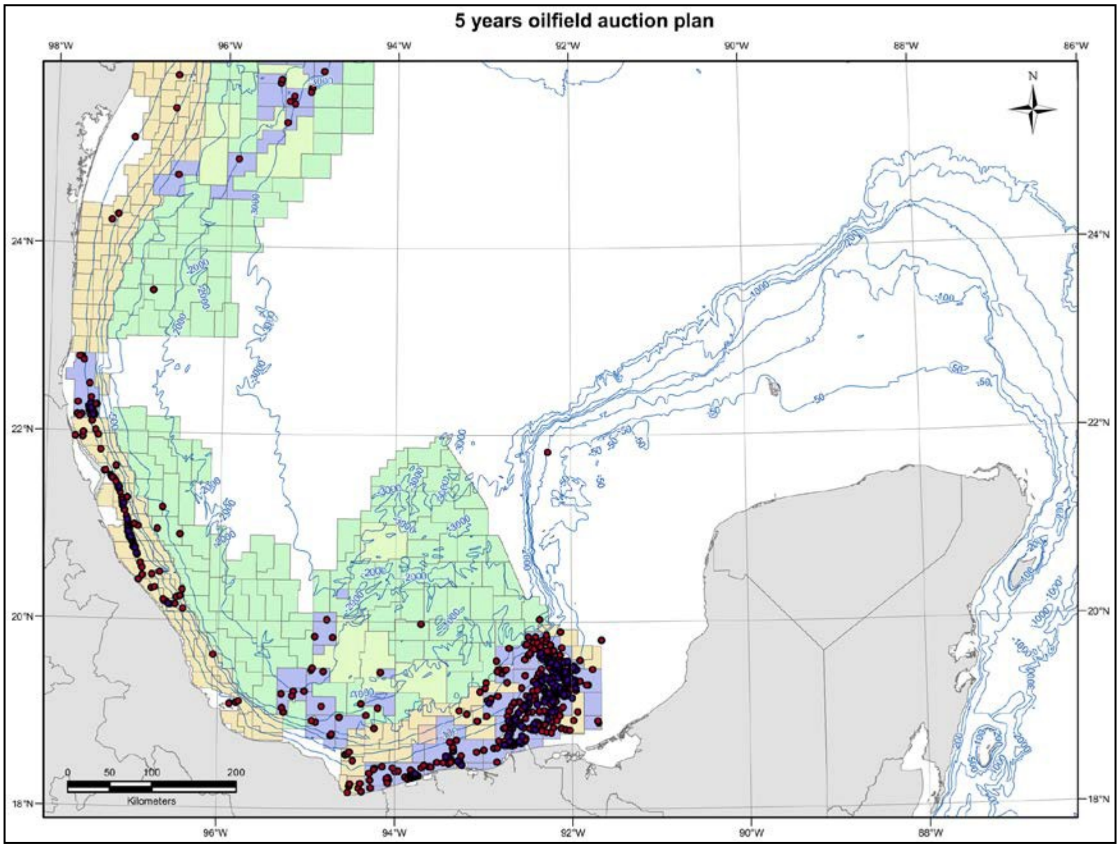

Figure 52. Map of the locations of lease blocks to be auctioned off by 2020.

The different colors indicate lease blocks that will be auctioned off together during each sale. From Simoes et al. (2016).

2.3.2 Using the Inventory

A series of maps were produced that allowed comparisons between sampling effort, species richness or taxon distribution, and information about current and future/potential hydrocarbon development.

2.3.2.1 Sampling Effort and Biodiversity

The pattern of benthic sampling effort through time indicates an increase during the last decades. Benthic sampling has focused on the shallow and coastal areas, especially in the current offshore oilfields area off Tabasco and southern Campeche (Figure 54). The large northern Yucatan carbonate basin has been sampled to some extent, however, the sampling point density is relatively low except in coastal areas, where data associated with octopus and sea cucumber fisheries is fairly concentrated. Generally speaking, coral reefs and cays are relatively well sampled and the deep sea is much less studied.

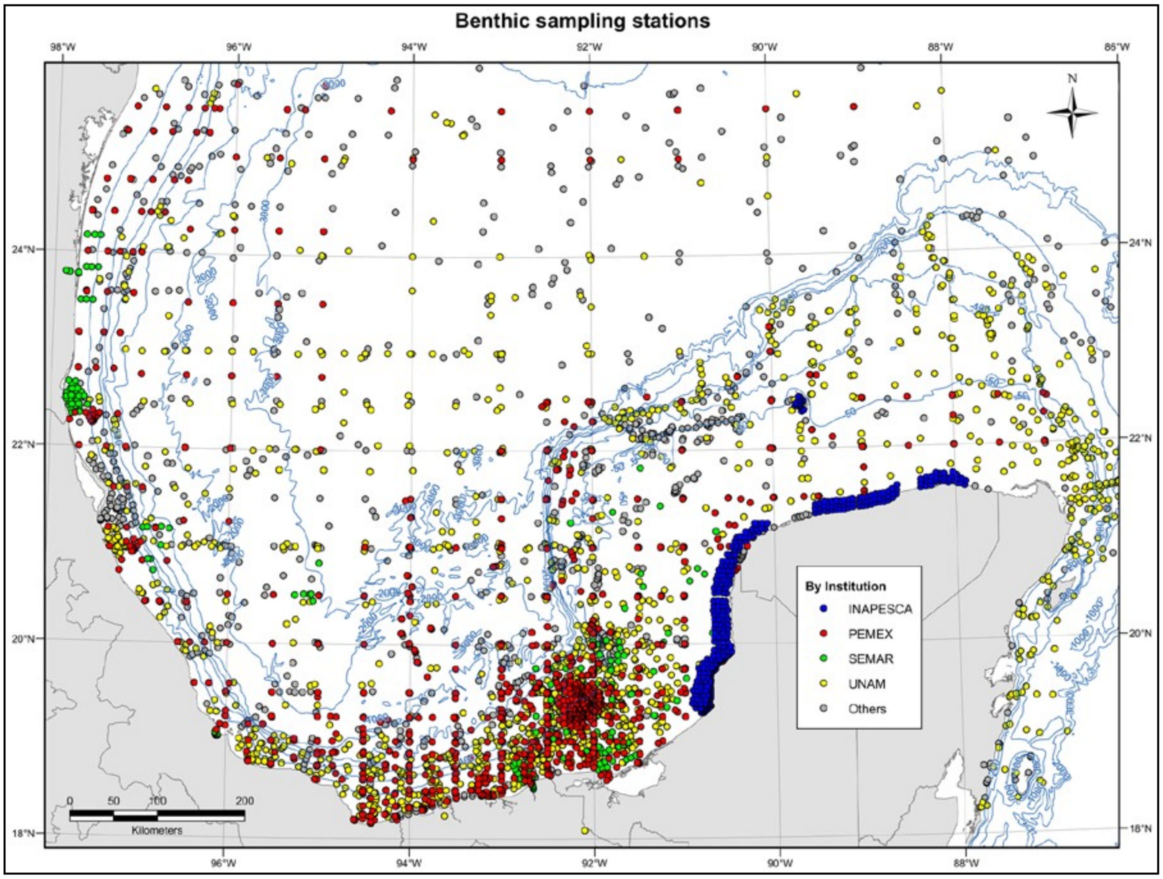

Figure 53. Map of benthic sampling stations by institution.

From Simoes et al. (2016).

The comparison between the distribution of benthic sampling stations (Figure 54) and relative species richness (Figure 55) shows the expected relationship between richness and sampling effort (more sampling = greater richness) but also shows that in many places that were sampled only a single species was recorded. More than 50% of the SGOM has no publicly-available data on species presence (Figure 56). There is also a great deal of variability as to whether benthic sampling data has related species data recorded or whether species data has related sampling data recorded (e.g., specific location; Figure 57). Clearly, there must be information from the areas where sampling has occurred, but in some cases there is no related species data recorded. Surprisingly, there are many species records that do not match with the reported sampling effort, especially in the deep sea where benthic sampling is very expensive. This has two possible explanations: not all species included in this study and herein mapped are benthic, and/or the sampling effort compilation is not complete or exhaustive.

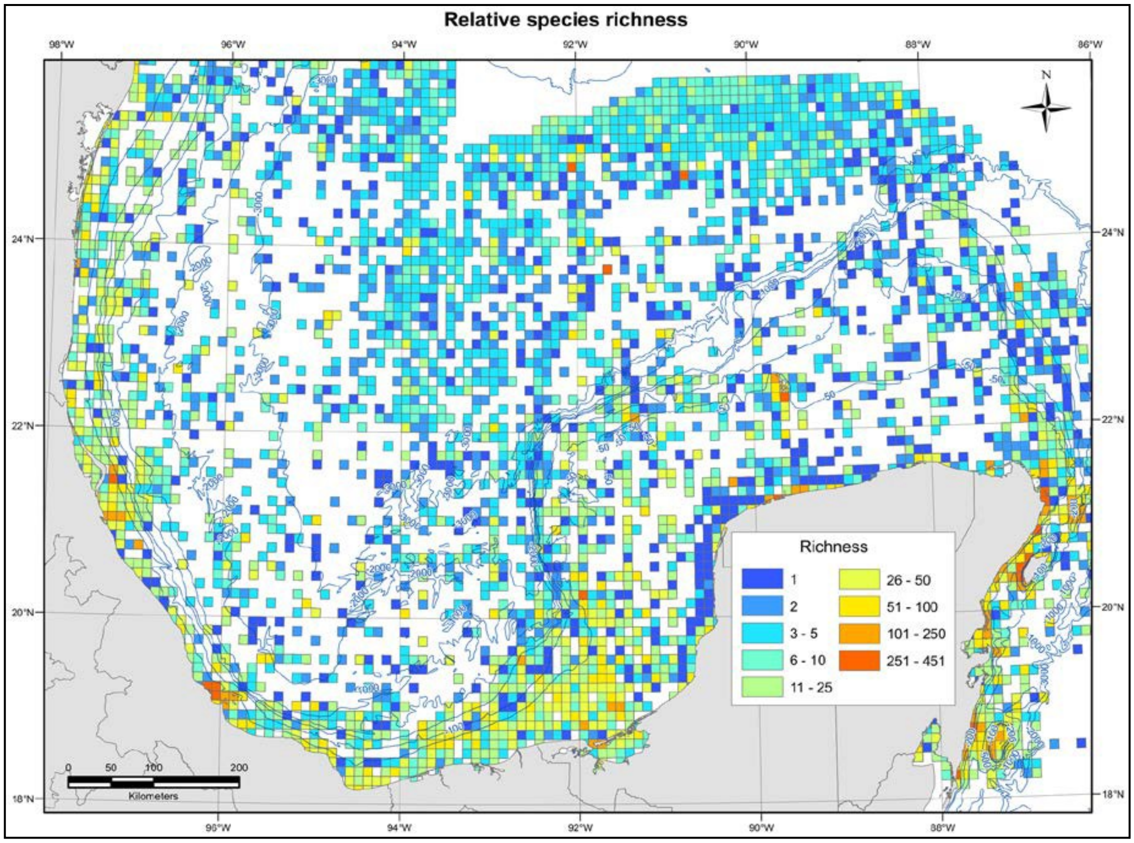

Figure 54. Map of species richness.

Values represent number of species. From Simoes et al. (2016).

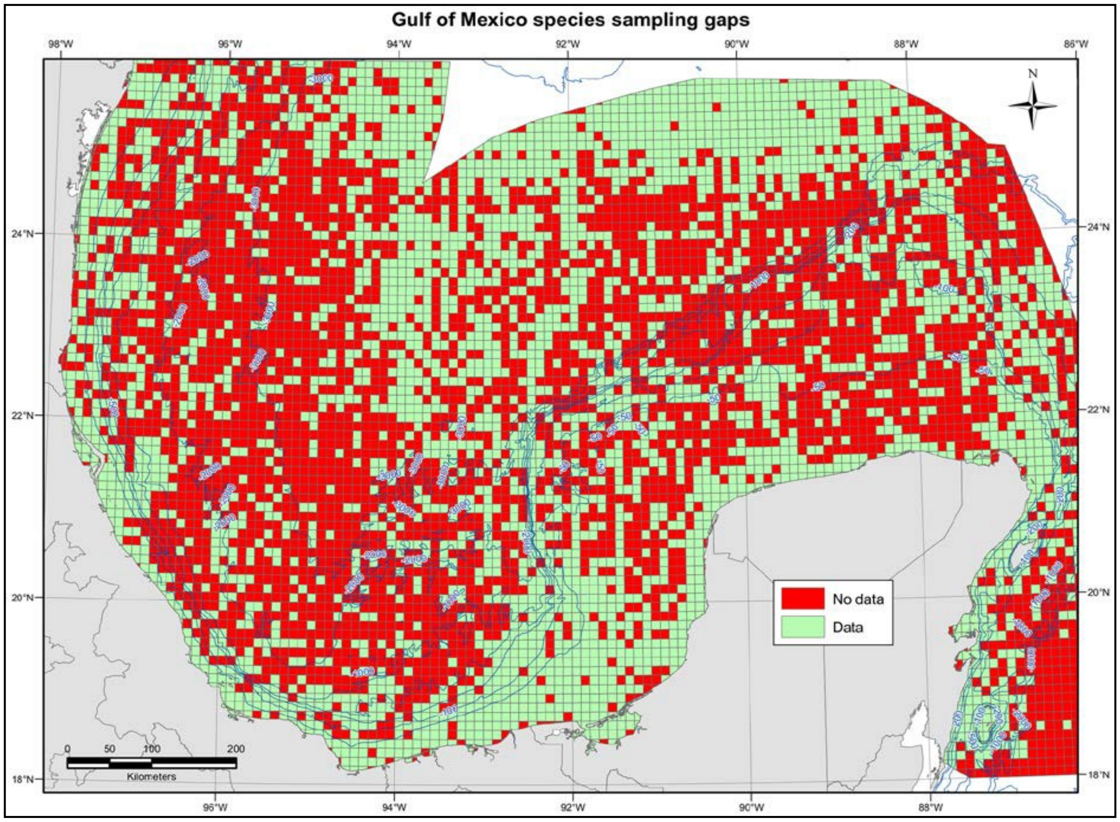

Figure 55. Map showing where data on species distribution do and do not exist in the GOM.

From Simoes et al. (2016).

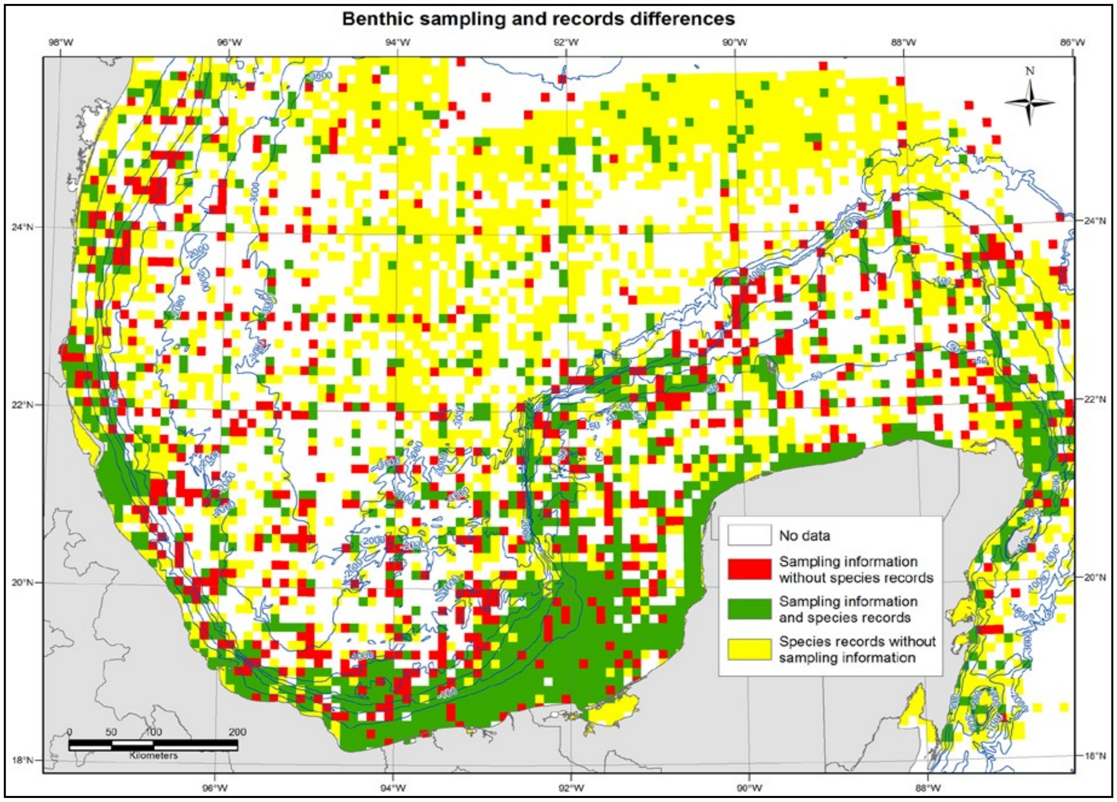

Figure 56. Map showing the distribution of sampling data (e.g., specific location) and species records.

From Simoes et al. (2016).

Some species may have a pelagic distribution of larva, but their adult form can only be found in the benthos and vice versa. The distinction between each species traits and their functional biology is not available for all species or even standardized, which inhibits division of the available information into smaller packages that are more useful for specific questions. For example, filtering the species by the category "benthic" in the classifications included in the different chapters of Felder and Camp (2009), did note xclude some pelagic species from the inventory. To best of our knowledge there isn't yet a centralized repository if this kind of information other than Felder and Camp (2009).

Another example is that all inventory species records from Laguna de Términos lack data on the location of the specific sampling points even though the lagoon has been extensively studied with many published reports that may contain data. The fact that there are many species records in areas where no sampling apparently occurred, suggests hidden historic information scattered in many academic institutions and state-federal government agencies. Some maybe possible to retrieve through an exhaustive search in the academic and grey literature, as well as direct contact with the institutional representatives to explore gaining access to otherwise classified information. It also indicates a lack of interest by researchers or research entities to log and curate the specific locations of their sampling sites.

Figure 58 is a map showing the preliminary oil "risk" index for the SGOM. A higher risk index is found in those areas where the risk for an exploration/production oil spill is higher and where there is less information available on the species present. In other words, higher risk areas are those where there should be effort expended to develop species inventories. Areas of current and future oil exploration/production are generally considered at high risk although areas with little species data, such as the yellow areas along Campeche Bank, where there are significant coral reef habitats, end up with a low-mid ranking, likely due to this lack of information. There is also a substantial amount of benthos on Campeche Bank that lacks biologic data of any kind.

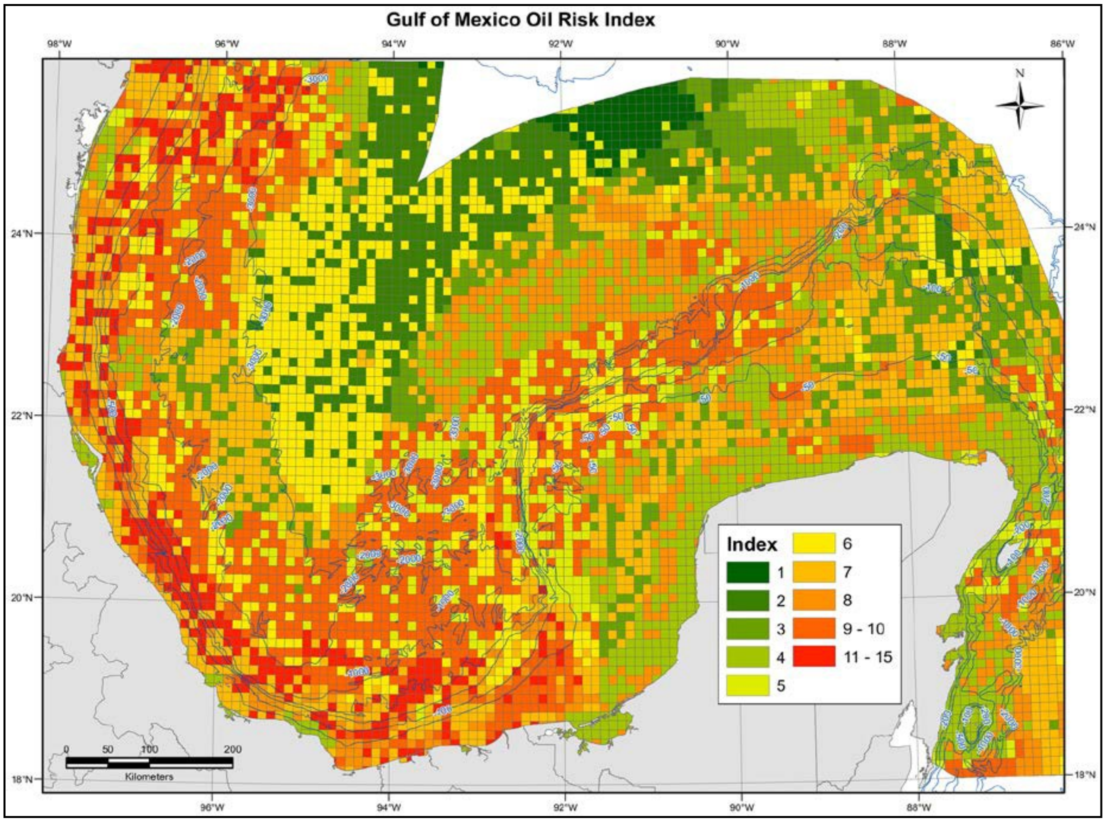

Figure 57. Preliminary “Oil Risk Index” map produced using the inventory.

Oranges and reds (higher numbers) equate to greater risk than greens and yellows (lower numbers). From Simoes et al. (2016).

Sampling in all areas is clearly too costly. Considering that many of the benthic habitats in the SGOM are relatively homogeneous and extensive, the species distribution modelling approach could be of great use to estimate the probability of a species to be present at a particular site. Models depend on good environmental data layers and on accurate species distribution information. Used together, these powerful models could contribute with products for effective management strategies.

2.3.3 Conclusions

Especially when coupled with mapping tools, the inventory provides data that can be visualized or modelled to address a variety of conservation and management questions. In this case, the maps produced using the inventory records clearly illustrate the large gaps in the existing records. That so few species records have sufficient metadata (e.g., exact location) clearly illustrates a need that current researchers should address. On the one hand, this kind of information cannot be re-created from the sources from which the data in the inventory have been taken, especially those sources that are decades old. On the other hand, these data are easily obtainable today with clearly defined metadata standards, and their collection should be part of every researcher’s protocol. In areas where there were data that contained both species presence and location data that overlapped with oil production, the oil risk index corresponded to what would be expected – high risk. In areas where there were no or few data and little oil production activity, the oil risk index settled in the middle.

The compilation of a marine benthic species distribution inventory in the SGOM and its use in conjunction with an oil-spill-risk index and map, helped identify those areas with a priority to develop, or update species inventories, before the projected expansion of Mexico´s offshore oil industry after the opening of the energy market in 2013. It also helped identify those institutions known to have conducted sampling in the past, but for which results are not yet publicly available, as well as demonstrating the need for a centralized repository on species traits and their functional biology. Finally, the bibliography screening exercise showed the potential to extract relevant species point-distribution data from old published information, although it will be time and labor intensive.

To fully exploit the potential of species distribution models to calculate the probability of a species occurrence at a particular site and time in the SGOM, we need:

- To complete the compilation of the benthic sampling effort historic time-series and update it with new information from recent species distribution sampling campaigns
- To extract historic species-point-distribution data from published literature and preserved specimens in scientific and museum collections
- To complete and make available classifications of all relevant species according to their traits and functional biology
- To develop a species interactions network and database

2.3.4 References

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2.4 Knowledge Gaps Identification

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2.4.1 Process

As was previously noted, the plenary sessions of the workshop were designed to help participants move into the working groups with a common knowledge of the state of international science in the GOM. The goals of the working groups were:

- To identify the pressing research needs/questions for the SGOM within each thematic area
- To discuss how bi- and trinational research networks might be developed

The process for organizing and structuring the working groups was planned by HRI representatives, facilitators, and other representatives from BOEM, NOAA, and NASEM-GRP over the course of several months and numerous conference calls during the last quarter of 2016 and March 2017. Working groups were organized into separate rooms by the three BOEM thematic areas (i.e., baseline studies, environmental monitoring, and fates and effects) and each working group had a facilitator from NOAA or NASEM-GRP and representatives from HRI who worked with facilitators to keep the working groups on track. Within each working group, the eight focus areas from the ESID database that were the focus of the inventory (i.e., coral and hard bottom, demersal fish, geology, infauna/meiofauna, pelagic ecology, seagrass, water quality, physical and oceanographic processes; some were combined in one or more of the working groups) helped participants organize by expertise, which facilitated the identification of unmet research questions or needs within each thematic area–focus area combination (see Appendix B). Focus- area groups within the working groups were provided with computers loaded with the draft inventory, a paper copy of the inventory specific to the working group's thematic area and large format paper worksheets to record the results of their summary of research needs within each focus area. Focus-area subgroups proposed research questions, and provided information about the research needs associated with these questions:

- What new data are needed to answer this question?
- What agency or organization is likely to collect this data?
- What existing data from the inventory can be used to answer the question?

After each focus-area group had reviewed the draft inventory, they generated a list of questions and identified potential resources available related to the data needs to answer the question. Then, each focus- area group designated a "Table Lead" that would remain at the table while the members of the focus-area group and other working-group participants were briefly rotated through the other focus areas. During these rotations, Table Leads briefed those who came to the table about the work that had already been accomplished. After the briefing, the new group of participants was asked if they had ideas or information to contribute related to items missing from the inventory, questions the focus-area group had already identified, or if they had additional research questions to add that were relevant to the focus area.

Once all working group participants within a thematic area had a chance to provide feedback to each of the focus-area groups, the focus-area groups reconvened to choose the questions that they felt were the most important to bring to their working group as a whole. Facilitators asked focus-area groups to limit the number of questions chosen from their list to three or four. A spokesperson for each group relayed the choices to the facilitator and the rest of the working group, and a list was compiled and projected on a screen so that the entire working group could see the questions. Then the working group as a whole discussed the list of questions, ultimately arriving at three questions that were either identified as the most critical within their thematic area or that could be merged into broader questions that addressed several questions that were common or similar among the focus groups within the thematic area. These questions were then presented at the closing plenary and represented the distillation of the work by each thematic- area working group.

At the end of the research question exercise, and prior to the final plenary, each working group had a brief discussion of how GOM research networks could be established and developed that would help foster collaboration among the scientists of Mexico, Cuba, and the United States.

2.4.2 Results

All of the questions, types of new data, existing data sources, and entities that might collect data generated by each of the thematic-area working groups and focus-area subgroup are available in Appendices 2.1-2.3. Each working group approached the prioritization of questions slightly differently, so the presentation of the questions by thematic area varies somewhat. The top-ranked questions that were presented to the final plenary tended to be syntheses of several questions from more than one, or sometimes all, of the focus areas. Thus, there is no direct correspondence (in most cases) between the top- ranked questions listed under each thematic area and the larger set of questions found in either the appendices or the initial list of priority questions generated by each working group.

2.4.2.1 Baseline Studies

The Baseline Studies working group identified 17 priority questions (Table 7) from the 85 questions submitted by the focus-area subgroups (Appendix B.1). Four questions/research needs were then identified from the list and were ranked:

1. What is the current distribution and variability of benthic habitats?
2. What is the Gulf-wide connectivity of species and communities across space and time?
3. Historical reconstruction of data from peer-and non-peer-reviewed sources across all languages.
4. Determing baseline of primary and secondary production at different temporal and spatial scales, and how it relates to trophic dynamics.

The participants in the working group noted two broad themes that ran through many questions. These themes suggested three broad priority research topics:

1. Spatial and temporal distribution and habitat mapping of all groups
2. Taxonomic and genetic inventory of all groups
3. Ecological and genetic connectivity in relation to circulation processes.

The 17 priority questions were subsumed under these broad priority research topics (Table 7). However, the participants were not satisfied with the very broad questions that they ended up with, because they were too broad to be informative. Thus, the group went back to the questions and synthesized some of them into more specific questions or research needs under two broad research categories, which included mapping studies and connectivity (Table 8).

Table 7. Identified priority questions, proposed by focus-area subgroups in the Baseline Studies working group organized by broad research themes

1. Spatial and temporal distribution & habitat mapping of all groups
    a. What meiofauna/infauna species are present at a regional scale?
    b. Longitudinal comparative baseline studies involving commercially and recreationally important fish species for entire Gulf.
    c. What are the processes driving the Loop Current intrusion, eddy separation, energy transfer from surface to the deep Gulf?
    d. What is the current distribution and variability of benthic habitats?
    e. What is the current distribution and connectivity of pelagic species?
    f. What are the local and regional impacts of sea-level changes in the GOM?
2. Taxonomic and genetic inventory of all groups
    a. What is the present land use and land cover and how has it changed over time?
    b. Can we increase the genomic database?
    c. Historical reconstruction of data from peer- and non-peer-reviewed sources across all languages in the Gulf
        i. Understand recreational fishing trends
    d. What are the baseline conditions of habitats in shallow and deep water and how have they changed over time?
    e. Connectivity studies of migratory and endangered species.
    f. Can we get access to existing bathymetric data and produce high-resolution maps of substrate types in the deep Gulf?
3. Ecological and genetic connectivity in relation to circulation processes
    a. What indicators and/or representative sites should be selected for targeted research monitoring to serve as proxies for the region? (seagrass and water quality)
    b. What is the temporal and spatial variability at different scales for community structure and species diversity? (Infauna)
    c. What is the connectivity of species and communities Gulf wide across space and time?
        i. What are the transfer rates of egg/larvae, ontogenetic migration of fish, and adult movement?
    d. What is the inventory of benthic habitat dependent species including genetics?
    e. Determining the baseline of primary and secondary production at different temporal and spatial scales and how it relates to trophic dynamics.

Table 8. Baseline Studies working group question "merge" representing the research priorities under two broad research categories—mapping studies and connectivity

1. Mapping Studies
    a. Improved mapping of benthic resources, habitat and fish abundance, on fine spatial scales
        i. Define nursery habitat/true ecoregions based on abiotic factors
    b. What is the current distribution and interannual variability of seagrass cover; what drives variability?
    c. Where are sensitive, natural, and artificial biologic benthic habitats (corals and hard bottoms)?
    d. What is the current distribution and variability of benthic habitats?
    e. What is the current distribution and variability of pelagic species?
2. Connectivity
    a. Connectivity studies of migratory and endangered species
    b. Connectivity of species and communities throughout the Gulf in space and in time
        i. What are the transfer rates of fish eggs/larvae?
        ii. How does ontogenetic migration of fish and adult movements connect habitats in space and in time?
    c. How do circulation processes drive ecological and genetic connectivity at varying scales?

2.4.2.2 Environmental Monitoring Studies

The focus-area subgroups submitted a total of 65 questions (Appendix B.2). In the discussion of the entire workgroup to choose the priority questions, there was a great deal of overlap in the broad themes of questions if not the specifics. Ultimately, 22 questions or research needs in four categories were identified by the working group (Table 9). The four categories of research needs were submitted to the final plenary, with the following broad questions:

1. What are the priority needs [in each category] for monitoring?
2. What are the most important variables [in each category] that determine changes in the Gulf?

Table 9. Priority questions proposed by focus-area subgroups in the Environmental Monitoring working group organized by broad research themes that were identified by the working group as a whole

1. Spatial and temporal distribution
    a. Predictive distribution modeling of infaunal/meiofaunal species habitat in the SGOM
    b. Locations, seasonality, and status of demersal fish spawning aggregations
    c. Distribution, role, and balance of lower trophic levels in SGOM (bacteria, plankton; carbon dynamics, primary production, microbial loops, HABs)
    d. Hypoxia
    e. Sufficient sediment distribution maps
    f. Benthic habitat types
    g. Effects of sea-level rise
    h. Recreational and commercial fish landings
    i. Nutrient inputs
2. Socioeconomic Considerations
    a. Assessment of coral resources
    b. Current conditions vs loss of ecosystem health: effects on fisheries, tourism and potential losses of income
    c. Conflicts and limitations between ecosystem health and economic development
    d. Water quality→ecosystem health→ecosystem services
3. Connectivity/Interchange
    a. Currents (esp. Loop Current) and distribution/connectivity of habitats, biota
    b. Intertidal→shallow water→deepwater: biota,
    c. Larval hotspots and the rest of the GOM
    d. Benthic boundary layer processes and water column, nutrients etc.
    e. Small scale and large-scale processes
4. Status
    a. Stony corals in SGOM; what are their restoration efforts and are they successful?
    b. Lionfish and other invasive species; impacts on the status of other species.
    c. Pelagic fish stocks
    d. Marine mammals, turtles, birds

2.4.2.3 Fates and Effects Studies

A total of 18 questions were identified by the working group as potential priority questions (Table 10) after discussing the more than 90 questions submitted by focus-area subgroups (Appendix B.3). This working group determined the priority questions by asking members to choose their top question. The four questions that received the most votes as the top priority were:

1. How do biota (individuals, communities, ecosystems) respond to environmental and anthropogenic impacts in space and time?
2. How are populations in the GOM connected via physical factors, chemical factors, and life stages?
3. How can environmental impacts be assessed without baseline data?
4. How do stressors, such as invasive species, ecosystem health, and sustainability, impact biodiversity?

Table 10. Priority questions proposed by focus-area subgroups in the Fates and Effects working group organized by overall ranking

Questions in bold were those that were submitted to the final plenary.

1. **What are the environmental and anthropogenic impacts and response on biota? Multiscale (individuals, communities, ecosystems) over space and time?**
2. **How are populations connected across the GOM ecosystem: physical, chemical, and life stages?**
3. **How can environmental impacts be assessed without a baseline?**
4. **What are the impacts of stressors on biodiversity, including invasive species, ecosystem health, and sustainability?**
5. What are the main sources of stressors on water quality in the SGOM and northern Caribbean Sea?
6. What are the vulnerable areas of coral, hard-bottom, and seagrass and how can they be quantified, understood, protected, and restored?
7. How do we evaluate the effects of environmental variables vs the effects of pollutants?
8. How could we develop national standards based on international best practices that involve calibration of different methodologies from different research focuses?
9. How do we manage cross-national fisheries (pelagic): population structure and the impact of pollutant mixtures?
10. What are the relationships between human activity and coral, hard bottom, and seagrass ecosystems?
11. What is the pelagic community structure and function across different Gulf habitats?
12. How can we use current observing capabilities to determine the eddy variability in the SGOM water column?
13. What are the impacts of fracking technology on water quality?
14. What are the seafood safety issues and associated human health impacts across regions?
15. Are demersal fish populations resilient to disturbance and how can it be tested?
16. What is the cross-shelf and along-shelf transport variability in the SGOM?
17. What are the atmospheric heat momentum and mass fluxes in the SGOM?
18. Does the Benthic Index for the Campeche Sound (BIC) work in the northern Gulf?

2.4.2.4 Network development

Each of the working groups discussed the following questions and compiled a list of recommendations:

1. How should Mexico, Cuba, and the United States work together [on issues related to the GOM] in the future?
2. How can a network of professionals and scientists be formed?
3. How can program planning activities and logistics be facilitated?

The answers provided by all three working groups are presented in Table 11, Table 12, and Table 13. Several themes emerged. First, the need for student and research exchange among countries was recommended as an answer to all three questions. One respondent noted that exchanges of graduate students are particularly important because they will begin building their networks with potential collaborators in the other countries early in their careers. Another theme was the need to develop bi- and trinational working groups, communities of practice, and data sharing mechanisms. This theme speaks to the heart of the mechanisms by which working relationships and trust can be built. Finally, the issue of funding was also pervasive. The success of efforts to develop bi- and trinational research infrastructures hinges on the availability of adequate funding and joint funding opportunities.

Table 11. Compilation of answers to question Question 1 concerning the development of research networks among Mexico, Cuba, and the United States to facilitate cooperation and collaboration on Gulf of Mexico research

Question 1—How should Mexico, Cuba, and the United States work together [on issues related to the Gulf of Mexico] in the future?

1. Identify specific sites/habitats/areas to be studied and invite interdisciplinary participation by researchers from throughout the Gulf of Mexico
2. Create international panel/intergovernmental panel/interagency panel/on Gulf of Mexico sustainability
3. Provide travel support and funding for bi- and trinational partnerships
4. Support joint funding calls (e.g., NSF/CONACYT, BOEM/Fondo Hydrocarbon) or other requests for proposals that require US-Mexico or US-Cuban collaborations
5. Collaborate on proposals
6. Promote peer-review publications with large, multinational collaboratives of Gulf of Mexico researchers
7. Identify funding sources, share funding resources, and publish papers together
8. Convene workshops where experts from all three nations would work together to produce white papers on the current status of a given problem
9. Establish an informal “International Commission of the Gulf of Mexico”
10. Hold in-country data workshops so that data could be presented and then added to a data repository, perhaps GRIID-C
11. Convene a working group to combine data from all sources to improve habitat classification and mapping throughout the Gulf of Mexico
12. Carry out joint stock assessments for shared stocks and comanage fisheries
13. Include SGOM in the NOAA Ecosystem Status Report
14. Organize exchange programs for scientists and students

Table 12. Compilation of answers to Question 2 concerning the development of research networks among Mexico, Cuba, and the United States to facilitate cooperation and collaboration on Gulf of Mexico research

Question 2—How can a network of professionals and scientists [working on issues related to the GOM] be formed?

1. Networking by general topics or research interests
2. Be efficient and use existing networks – for example, Facebook, ResearchGate
3. Create topical workshops to provide a venue for experts to meet and collaborate and for nonexperts to learn
4. Create a structure similar to the CloTOP program which operates worldwide—it has no dedicated funding but has been very successful
5. Invite more scientists to submit a profile to GulfBase so that people can contact potential collaborators more easily
6. Have GulfBase in both English and Spanish
7. Turn GoMOSES conference into the Gulf of Mexico International Science Conference
8. Student and researcher exchanges
9. Standardize Gulfwide monitoring methods and protocols
10. Form an association of marine laboratories in the Gulf of Mexico similar to the National Association of Marine Labs (NAML) in the United States
11. Build communities of practice around subject matter expertise
12. Create a trinational version of Texas OneGulf

Table 13. Compilation of answers to Question 3 concerning the development of research networks among Mexico, Cuba, and the United States to facilitate cooperation and collaboration on Gulf of Mexico research

Question 3—How can program planning activities and logistics be facilitated?

1. Develop trinational working groups for specific issues
2. Funding opportunities that will allow scientists from all three countries to meet
3. Hold an annual conference (or side meeting at an existing meeting) that rotates between the United States, Cuba, and Mexico, e.g., ONEGULF Summit.
4. Offer field trips at meetings to foster collegiality and so that scientists can learn more about the other areas of the Gulf of Mexico.
5. Carry out joint research cruises to maximize ship time, facilitate collaborations, etc. and include multiple projects on a cruise, if possible
6. Student and researcher exchange programs
7. Strategy exchange with partners that addresses management, science, education, hydrocarbon development, and MPA issues
8. Agree that if autonomous scientific equipment roams into waters of the other Gulf of Mexico countries that it will be allowed to swim home
9. Allow cross-border transport of scientific specimens and research equipment
10. Bi- and trinational data sharing, especially stock assessments of shared fisheries stocks

2.4.2.5 Final Plenary

The entire workshop reconvened in a final plenary session so that facilitators could give a brief presentation of their working group's research priorities. Though not unexpected, all three working groups submitted research priorities that addressed overarching themes of biotic and abiotic connectivity, status and distribution of biotic and abiotic components, and effects of stressors. Perhaps the best description of the priority research needs in the GOM was the final question posed by the baseline studies working group: "What's where and how does the Gulf of Mexico work?"

Appendix A: Participant List

Participant list with assigned working group: B = baseline studies, EM = environmental monitoring, FE = fates and effects studies. Floaters were participants that were not preassigned to a working group but who participated in several working groups.

First Name	Last Name	Affiliation	Group
Alfonso	Aguilar-Perera	Universidad Autónoma de Yucatán	B
Porfirio	Álvarez Torres	Interdisciplinary Centre of Marine and Environmental Research (CIIMAR)	B
Rainer	Amon	Texas A&M University at Galveston	B
Maickel	Armenteros	Centro de Investigaciones Marinas – Universidad de La Habana	B
Mark	Besonen	Harte Research Institute	B
Fernando	Bretos	The Ocean Foundation/Patricia and Phillip Frost Museum of Science	B
Debra	Butler	National Academies of Sciences, Engineering, and Medicine, Gulf Research Program (NASEM-GRP) Science Policy Fellow	B
Sharon	Chinchilla	University of Miami/CARTHE Consortium	B
Greg	Easson	University of Mississippi	B
Juan Ramón	Estrada Camacho	Instituto Mexicano del Transporte (IMT-SCT)	B
Lane	Foil	Louisiana State University	B
Guillermo	García Montero	Acuario Nacional de Cuba y Comité Oceanográfico Nacional	B
Blanca Idalia	González Garza	Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV-IPN)	B
Ruoying	He	North Carolina State University (NCSU)	B
Sharon	Herzka	Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)	B
William	Heyman	LGL Ecological Research Associates, Inc.	B
J. Derek	Hogan	Texas A&M University-Corpus Christi	B
Guillermo	Horta-Puga	FES Iztacala, Universidad Nacional Autónoma de México	B
Xinping	Hu	Texas A&M University - Corpus Christi	B
Samantha	Joye	University of Georgia	B
Mandy	Karnauskas	NOAA Fisheries Southeast Fisheries Science Center (SEFSC)	B
Greg	Kozlowski	Bureau of Ocean Energy Management (BOEM)	B

First Name	Last Name	Affiliation	Group
Kirsten	Larsen	NOAA NESDIS/NCEI Oceanographic & Geophysical Information Services Branch	B
Hui	Liu	Texas A&M University at Galveston	B
M. Cecilia	López Castro	Pronatura Península de Yucatán, A.C.	B
Alexis	Lugo-Fernandez	Bureau of Ocean Energy Management (BOEM)	B
Ian	MacDonald	Florida State University	B
Lázaro	Márquez Llauger	Parque Nacional Guanahacabibes	B
Timothy	McCune	Bureau of Ocean Energy Management (BOEM)	B
Luke	McEachron	Florida Fish and Wildlife Research Institute	B
James	Moore	Bureau of Ocean Energy Management (BOEM)	B
Steven	Murawski	University of South Florida	B
Stephanie	Norman	Marine-Med: Marine Research, Epidemiology, & Veterinary Medicine	B
Daniel	Pech	El Colegio de la Frontera Sur	B
Horacio	Pérez-España	Universidad Veracruzana	B
Harriet	Perry	University of Southern Mississippi	B
Henry	Potter	Texas A&M University	B
Melissa	Rohal	Harte Research Institute	B
Steven	Saul	Arizona State University	B
George	Schmahl	NOAA Flower Garden Banks National Marine Sanctuary	B
Nuno	Simoes	Universidad Nacional Autónoma de México (UNAM)	B
Rob	Smith	Woods Hole Group	B
Stephen	Trumble	Baylor University	B
Diana	Ugalde	Universidad Nacional Autónoma de México (UNAM)	B
Daniel J.	Warren	Oceaneering International	B
Gary	Wolinsky	Chevron Energy Technology Co.	B
Lad	Akins	Reef Environmental Education Foundation (REEF)	EM
Jerald	Ault	Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of	EM
Jorge	Brenner	The Nature Conservancy	EM
Laura	Carrillo	El Colegio De La Frontera Sur	EM
Billy	Causey	NOAA Office of National Marine Sanctuaries	EM

First Name	Last Name	Affiliation	Group
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First Name	Last Name	Affiliation	Group
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Rodney	Cluck	Bureau of Ocean Energy Management (BOEM)	EM
Steven	DiMarco	Texas A&M University	EM
Elva	Escobar	Universidad Nacional Autónoma de México - Instituto de Ciencias del Mar y Limnología (UNAM-ICML)	EM
R. Alexis	Fernández Osorio	Acuario Nacional de Cuba	EM
Xavier	Flores Vidal	Universidad Autónoma de Baja California (UABC)	EM
Simon	Geist	Texas A&M University-Corpus Christi	EM
S. Patricia	González Díaz	Centro de Investigaciones Marinas de la Universidad de La Habana	EM
Maria	Hartley	Chevron	EM
Read	Hendon	Gulf Coast Research Laboratory, School of Ocean Science & Technology	EM
J. Carlos	Herguera	Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) & Consorcio CIGoM	EM
Robert	Hueter	Mote Marine Laboratory	EM
Syed	Khalil	Coastal Protection & Restoration Authority of Louisiana	EM
Bill	Kiene	NOAA Office of National Marine Sanctuaries	EM
Barbara	Kirkpatrick	Gulf of Mexico Coastal Ocean Observing System (GCOOS)	EM
Tony	Knap	Texas A&M University	EM
José Vinicio	Macías Zamora	Instituto de Investigaciones Oceanológicas (IIO)-Universidad Autónoma de Baja California (UABC)	EM
Tim	McClinton	David Evans and Associates, Inc.	EM
Mark	Mueller	Bureau of Ocean Energy Management (BOEM)	EM
Gabriel	Núñez-Nogueira	Universidad Juárez Autónoma de Tabasco	EM
Juliano	Palacios Abrantes	The Institute for the Oceans and Fisheries, University of British Columbia	EM
Bonnie	Ponwith	NOAA Fisheries Southeast Fisheries Science Center (SEFSC)	EM
Cynthia	Pyc	JASCO Applied Sciences	EM
Nancy	Rabalais	Louisiana State University and Louisiana Universities Marine Consortium	EM
María	Serrano Jerez	Acuario Nacional de Cuba	EM

First Name	Last Name	Affiliation	Group
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John	Tirpak	US Fish and Wildlife Service	EM
Sarah	Tsoflias	Chevron USA Inc.	EM

First Name	Last Name	Affiliation	Group
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Travis	Washburn	Harte Research Institute	EM
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Ma. Leopoldina	Aguirre-Macedo	Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV-IPN)	FE
Francisco	Beron-Vera	Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of	FE
Donald	Boesch	University of Maryland Center for Environmental Science	FE
Victoria	Broje	Shell Exploration & Production Company	FE
William	Brown	Bureau of Ocean Energy Management (BOEM)	FE
Edward	Buskey	University of Texas at Austin	FE
Michael	Carron	Gulf of Mexico Research Initiative (GoMRI)	FE
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Benny	Gallaway	LGL Ecological Research Associates, Inc.	FE
Gerardo	Gold Bouchot	Texas A&M University	FE
Adolfo	Gracia	Universidad Nacional Autónoma de México - Instituto de Ciencias del Mar y Limnología (UNAM-ICML)	FE
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Chris	Kelble	NOAA Oar Atlantic Oceanographic & Met Lab	FE

First Name	Last Name	Affiliation	Group
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First Name	Last Name	Affiliation	Group
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Frank	Parker	NOAA RESTORE Act Science Program	FE
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Victoria	Ramenzoni	Harte Research Institute	FE
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First Name	Last Name	Affiliation	Group
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Melissa	Brewer	Harte Research Institute	Floater
Russell	Callender	NOAA National Ocean Service	Floater
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First Name	Last Name	Affiliation	Group
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Cara	Cooper	Gulf of Mexico University Research Collaborative (GOMURC)	Floater
Kristen	Dwyer	Harte Research Institute	Floater
Chris	Elfring	National Academies of Sciences, Engineering, and Medicine, Gulf Research Program (NASEM-GRP)	Floater
Maritza	García García	Agencia de Medio Ambiente (Environmental Agency)–CITMA (Ministerio de Ciencia, Tecnología y Medio Ambiente)	Floater
James	Gibeaut	Harte Research Institute	Floater
Rebecca	Green	Bureau of Ocean Energy Management (BOEM)	Floater
Emma	Hickerson	NOAA Flower Garden Banks National Marine Sanctuary	Floater
Julien	Lartigue	NOAA RESTORE Act Science Program	Floater
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Larry	McKinney	Harte Research Institute	Floater
Richard	McLaughlin	Harte Research Institute	Floater
Paul	Montagna	Harte Research Institute	Floater
Roberto	Pecero Neuman	Agencia de Seguridad, Energía y Ambiente (ASEA)	Floater
Rafael	Puga	Centro de Investigaciones Pesqueras La Habana, Cuba	Floater
Lauren	Showalter	National Academies of Sciences, Engineering, and Medicine, Gulf Research Program (NASEM-GRP)	Floater
Gail	Sutton	Harte Research Institute	Floater

First Name	Last Name	Affiliation	Group
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David	Yoskowitz	Harte Research Institute	Floater

Appendix B: Proposed Research Questions and Necessary New Data

B.1. All research questions developed by the Baseline Studies working group, including new data needed to answer the questions, entities that are likely to collect the data, and relevant existing data in the inventory.

B.1.1 Subject Category: Corals & Hard Bottoms

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Where are the sensitive biological components? Benthic habitats (natural and artificial)?	Review of existing oil and gas data; new surveys to locate new areas; oral histories with fishermen	Research Groups - UNAM, UV, CINVESTA, Mérida	Search O&G data
What is known about genetic/ecological connectivity among reef populations?	1) Collect tissue samples of flag species. 2) Do genetic studies. 3) Correlate information among reef sites	BOEM, NOAA, UNAM, UV	Smithsonian genetic database
What is the impact of high suspended solids on populations/communities in the Southern GOM's reefs?	1) Look for reefs not influenced by sedimentation like Florida, Campeche Bank, or Cuba. 2) Compare performance of Flag species 3) Characterize land use	BOEM, NOAA, UNAM, UV, CIM/Univ. of Havana	Community structure data is available for several Southern GOM reefs; AGRRA reports
Is the inventory of reef species finished in the Southern GOM?	1) It is necessary to continue the collection of specimens almost in all reef sites 2) Also to involve more taxonomists	UNDM, CINVESTAV, UV	CONABIO, ICMyL databases; CINVESTAV
Are shipwrecks and platforms acting as artificial reefs in the Southern GOM as they are in the northern GOM?	Locate and document shipwreck sites; Develop shipwreck database; Investigate platforms and artificial reefs for comparison	BOEM, NOAA, UNAM, Veracruz Port Authority; INAH, UV, National Fisheries Institute of Mexico	Grounding database 1950s-2016 (Mexico) AWOIS; Artificial Reef programs
How is erosion facilitating the decline of reef growth and reef related species while promoting algae reef growth?	Establish control study sites; Water quality sampling over sites; Program for repeated sampling; Bio-erosion testing	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the spatial pattern of diseases, bleaching, and coral coves?	Collect initial data; Develop long-term program - yearly at end of summer	BOEM, NOAA, U.S. State Fisheries, UV, UNA	Previous monitoring data to assess historical changes
Condition of reefs changed over time - shallow/deep	Coral cover and abundance; fish abundance and size; Aims and AGRRA monitoring; squid pots fisheries production monitoring; acoustics	UNAM, UV, UADT	AGRRA; REEF
What is the baseline acoustic environment of the sensitive habitats?	Baseline soundscape of specific reefs/habitats	UNAM, UV, UADT	NOAA?
Are shipwrecks and platforms acting as vectors for invasive species?	–	–	–
What are the impacts of bottom temperatures on sensitive species?	–	–	–
How is the sediment influx from the larger Gulf region impacting the sensitive habitats?	–	–	–

B.1.2 Subject Category: Infauna/Meiofauna

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the species in the Gulf (regional scale)?	We need species list data to fill in gaps regionally. We also need corresponding taxonomic work.	Most information from academic sources	Varied data/ references from inventory
Can we increase the genomic database for known species?	We need new/fresh samples for DNA analysis. Preserved samples are not useful.	Academic sources again; lesser part environmental agencies??	Some inventory references are using eDNA already
What are the scales of temporal variablility for community structure/species diversity?	We need to start monitoring projects to document this. We need fresh samples and processing power to handle this.	Academia	Varied
What is the functional role of infauna/meiofauna?	Field and experimental studies	Academia	Varied
What ecosystem services are provided by infauna/meiofauna?	We need field and socioeconomic studies	Academia	Varied
How do infauna/meiofauna contribute to systemwide productivity?	We need to analyze data we already have, but also supplement them with new studies	Academia	Unknown
Connectivity among populations on seafloor communities	–	–	–
What are the fauna associated with sargassam?	–	–	–
Which is the meiofauna/infauna in mesophotic coral reefs?	–	–	–

B.1.3 Subject Category: Demersal Fish

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Mapping of benthic resources (habitat) and fish abundance distributions across the entire Gulf of Mexico - on a fine spatial scale - fill holes between existing studies.	Bathymetry and habitat characterization (perhaps using drop camera gear). Create a "fish base" inventory of the Gulf of Mexico	Interagency, and intergovernmental collaboration, where each group contributes personnel and funds, including academics	Hold workshop on mapping or habitat characterization to identify gaps, and see if data can be combined to help keep maps current
Historical reconstruction of data by reviewing all journals and manuscripts, both peer review and not, in English and Spanish	Develop "State of and History of GOM Resources" authored by experts from each country.	Academic institution led most likely	Review historical
Connectivity of species and communities around the entire Gulf i.e. what are the distributions across space and time, and abundances, and what factors drive these distributions?	Genetics data, egg and larval dispersal models	Academics, NOAA, Mexican and Cuban partners	–
What is the distribution of fish larvae across the Gulf? What is adult connectivity?	Satellite data, current models, etc.	Academics, NOAA, satellite data	See modeling efforts of Claire Paris - Univ. of Miami; See also Mandy Karnauskas
Gather recreational fishing data for all 3 countries. Tease out recreational from subsistence and collect data on both	Landings, age structure and length structure of catches	Government agencies	–
How to balance needs of humans and ecosystems?	–	–	–
What are regulatory processes in all 3 countries that are effective management and ineffective management i.e. what works and what doesn't with respect to human needs and ecosystem?	Collect data on socioeconomics	–	Satellite primary productivity
Are there true eco-regions, substrate differences? What would layers go into categorizing regions?	Shallow and deepwater maps needed for Southern Gulf	–	–
Gather baseline data on deepwater Gulf: inventory, connectivity with shallow species i.e. abysal plane of Gulf, if another spill, how would it affect deep species?	–	BOeM, BP, Shell, Chevron, Exxon, etc.	–
Role of sargassum in Gulf of Mexico and its role in connectivity, larval fish survival, etc.	–	–	–
What is more important to fish connectivity: transfer roles of egg/larvae, ontogenetic migration or adult movement?	–	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Transboundary assessment of shared stocks across the GOM LME: Cuba, Mexico and United States.	–	–	–
Do we know all of the fish species that live in the Gulf?	–	–	–
Importance of estuaries to fish stocks, and quality of estuaries, and whether poor quality estuaries affect adult populations offshore	–	–	–
Define nursery habitat/regions/areas for Gulf of Mexico (i.e. seagrass, mangroves)	–	–	–
Comparative sites and entire GOM LME where you do longitudinal sampling for comparison purposes	–	–	–
Understand larval stages, and phenology of coral ref fish recruitment - implications for oil spill effects, etc. that may affect plankton/surface water	–	–	–

B.1.4 Subject Category: Pelagic Ecology

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Identification of critical habitats of different life stages of commercially important and endangered species	Centralized information of areas and species	–	–
How many no-take fishing zones exist? Do they work? Do they contribute to fish/coral conservation?	Fish aggregation areas; no-take fish areas inventory	CONANP; INAPESCA; Universidad Veracruzana	Unsure
Role of sargassum in the ecosystem, distribution and abundance	Distribution and movement of sargassum beds	CINVESTAV-CIGOM	None Found
Basic Biology of commercial and endangered species	–	–	–
Impacts of chronic oil pollution	Whole body assays; study design for sampling	NOAA, GOMRI, NAS	–
What supports primary and secondary production at different temporal and spatial scales/food web structure & dynamics?	–	–	–
Significance and importance of invasive species	–	–	–
Connectivity studies of migratory and endangered species	–	–	–
Longitudinal comparative studies involving commercially and recreationally important fish species (tri-national)	(individual & population level) Fish & species stress, health indices, reproductive data	Academic & NGO (Baylor, COBI)	None exists

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Population genetics and connectivity studies of migratory and endangered species	Molecular markers (microsatellites, mtDNA, etc.)	Academic & NGO (CiGOM)	Numerical modeling (currents)
Joint stock assessments of commercially important fish and recreationally important fish	Comparable data sets	NOAA/NMFS; INA PESCA; & Cuban equivilant	None Found
Health indices of marine mammals (e.g., microbiome, documenting fishery interactions, pollutants) based on strandings	Collecting stranded marine mammals through coordination of trinational stranding response networks	NOAA/NMFS; INA PESCA; & Cuban equivalant; Mexico - individual response groups, Dr. Eduardo Morteo, Universidad Veracruzana - Blood analysis of dolphins in Cuba database, Acuario Nacional de Cuba	None Found

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Harmful algal blooms, mechanisms of formation and species distribution	https://redfan.cicese.mx/	REDFAN; GEF - Alejandra Navarrete	None Found
Documenting microbial communities and microbial processes	Gulfwide surveys with genetic markers	CIGOM Dra. Leopoldina Aguirre; University of Georgia, Samantha Joye; Liliana Pardo IBT; Alexei Licea, CICESE; José Quinatzin García Maldonado, CINVESTAV	None Found
Linkages between deep sea and coastal waters	–	Academics	–
What are the impacts of temperature anomolies on the ecosystem?	–	Academics	–
Food web dynamics in the pelagic zone. Identify stressors on food sources for commercially and recreationally important species	–	Academics	–

Primary production and reproduction hot spots monitoring, identification, and protection	Imaging data	Heyman, W. LGL	None Found

B.1.5 Subject Category: Water Quality & Seagrasses

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Is there aquaculture or expected growth in aquaculture and what are the outcomes (potential)?	Economic data on aquaculture locations	–	–
How does sediment loading vary and what factors drive that variation? Positve - marsh accretion; negative - lower(?) seagrass	Sediment loads from major rivers/tributaries (can be remotely sensed); Factors: dredging, shrimp net dragging	–	–
How does gradual sea-level rise impact distribution of seagrasses (e.g., tidal flats being replaced by seagrasses)?	Distribution data over time with elevation/bathymetric data	–	–
How do low frequency but high impact events like hurricanes influence baselines? Are shifts temporary or permanent?	Before and after datasets for hurricane impacted regions	–	–
What indicators and/or representative sites should be selected for targeted and monitoring research to serve as a proxy for region?	–	–	–
What is the relationship between development, water quality, and seagrass cover?	Percentage of waste water treated and how that is changing over time	–	–
How does seagrass influence carbon cycling/carbon sequestration & where is it located?	–	–	–
What are the species-specific tolerances to salinity, temperature, water quality, and seagrass cover?	Factorial experiments; Look at tolerances	–	–
What is the proper scale for mapping seagrasses?	Data at different scales matched to degree of fragmentation	–	–
What is present land use/land cover and how is it changing over time (drives water quality changes)?	Data is already being collected; Analysis is the issue along with the resolution of remotely sensed data	–	–
How is water quality changing over time?	Continual monitoring of water quality (permanent system)	CONAGUA (Water Commission); IMTA (Water Technology Insi); SEMARNAT SEMAR (Ministry of Navy)	CONAGUA; IMTA datasets; SEMAR
Mangroves are an important habitat. Do they fit into this subgroup?	–	–	–
What drives interannual variablility in seagrass cover?	Regular monitoring at specific sites over time	–	–

How do winter storms impact seagrass?	Winter data on wave energy and changes in seagrass cover	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What level of wastewater treatment occurs in the region and how will that change over time? What is the impact on water quality?	Comprehensive dataset on waste water treatment and monitoring of outfalls, especially during storms that push out lots of untreated storm water runoff	–	–
What percentage of nutrient loading is from groundwater discharge?	–	–	–
What is the role of epiphytes and organisms associated with seagrasses in nutrient processing within seagrass beds?	–	–	–
What is the current distribution of seagrasses? How does it vary interannually? What drives that variability (natural and anthropogenic)?	–	–	–

B.1.6 Subject Category: Geology & Physical Processes

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Compile long-term bottom temperature records from deep sea	Need for additional moorings	ASEA should require EIS performed by Mexican academia; CONACyT, NOAA, BOEM, Industry, GOMRI, Academia, NSF, CICESE/CiGOM, ICML	Comb existing reports for unpublished records; CICESE…?
Ventilation of deep Gulf	CFCs; Maintain deep moorings	NSF, BOEM, NOAA, Industry, GOMRI, TAMU, CICESE/CIGOM	Deep Moorings 2006-2016
Loop Current Intrusion and eddy Separation, Energy transfer to deep	Mass balance between Yucatan Channel and FL Straits	NAS, BOEM, NOAA, Industry, Academic, CICESE/GiCOM/Rosentheil ICML	Loop study from BOEM Modeling output
General circulaton models to inform carbon fluxes	verify models, biogeochemical models, hydrogen & carbon fluxes using long-term moorings	NSF, BOEM, NOAA, GOMA, NAS, Industry, CICSESE	Existing model output; Nitrogen & Carbon Date (CIGOM); Existing moorings

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
How existing shelf data can be employed to study deep water. Assess/study sediment routes, distribution in time.	Shelf and slope concurrent measurements to establish link(s).	NOAA, Mexican Government, CICESE, ICML	Mexican Inst. Of Transport, PEMEX
High Resolution Bathymetry; Major issues/gap is access to existing data; Include substrate types in the deep Gulf	–	PEMEX; Industry; Government; University of Tamaulipas Institito Mexicano Del Petroleo Secretaria de Marina	Access to existing data!!!
SAR Climatology of Sea State	None	NASA, NOAA	SAR Images in NESDIS (NOOA)
Sea-level impacts for SGOM; What are the local and regional impacts of sea level changes in the Gulf?	Tide guage; Coastal morphology; Data access; Lidar	USGS/NOAA, NSF, UNAM, SEMAR, INECC, CiiMAR-GOMC	UNAM, NAVI

B.2 All research questions developed by the Environmental Monitoring working group including: new data needed to answer the questions, entities that are likely to collect the data, and relevant existing data in the inventory

B.2.1 Subject Category: Corals, Hard Bottoms, & Seagrasses

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the status of stony corals in the SGOM? What restoration is in effect? What is the efficacy of restoration?	Spatial distribution of stony coral; reef fishes; role of habitat; cover depends on life stage of fish	Collaborative effort of country's agencies, government agencies, universities, research centers	Some mapping in the US; NOAA; Nature Conservancy in the Gulf
Status of reef fish resources in the region?	Fish spawning information (gap)/aggregations	SEMARNAT-CONABIO	–
Where are fish spawn aggregation spots? What are their geomorphological characteristics?	Physical flow geomorphology; Understanding gyres and eddies	–	–
Interconnectivity of currents in the Gulf and how it drives habitat connectivity?	Genetic exchange; Population dynamics	–	Nature Conservancy - larval dispersion model

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Analyze connectivity between shallow and deep-water coral systems	–	–	–
Assessment of management of protected areas? Are they working for particular species?	–	–	–
Extent and effects of coral disease/bleaching events/climate change	Temperature; Salinity; Coverage; Rugosity	–	–
Status and recovery of *Diadema* in hardbottom habitat plus other indicator organisms	*Diadema*	–	–
Socioeconomic assessment of coral resources	–	–	–

B.2.2 Subject Category: Infauna/Meiofauna

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Laguna Madre de Tamaulipas, Laguna Tamiahua and other small lagoon systems, Laguna La Mancha, Alvardo area	Anything seagrass cover, etc.; Sediment quality, benthic or epibenthic	–	Nothing to speak of; some Laguna Madre de Tamaulipas data
Holistic overview of Gulf benthic boundary	Any biological data at boundary	NOAA; University	Some, especially OCS STOCS, Less in Southern GOM
How do you use genomics to inform decisions?	Tissues	USGS; BOEM; NOAA; NSF & Smithsonian; GGI-Oceans	Nothing
Predictive distribution modeling especially in SGOM (species habitat)	More species data	NOAA; University Genome groups	Some species data distribution; OBIS
Assessments of stress-prone benthic communities, especially acute stresses vs chronic affects	Some ongoing experiments at different time scales, Campeche	INAPESCA; Universities; GOMRI	Ongoing experiments
Sea level effects (climate change) on intertidal communities	Comparison of intertidal community	–	Some, not much
Connectivity with Shoreline ⟷ Open Ocean	–	–	–
Developed vs Underdeveloped Shorelines (mangroves-beachy)	–	–	–
Fishery species - Benthic conch-lobster whelk-seacucumber - urchin	–	–	–
How do larval hotspots disperse into the Gulf as a whole?	–	–	–
Temporal dynamics at any scale	–	–	–

B.2.3 Subject Category: Demersal Fish

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are deepwater Lionfish populations & impacts?	–	–	–
What are trends in diversity age/growth & reproduction of fish over time?	–	–	–
What are populations and impacts of non-native damsel (*N. cyanomos*) in the Western Gulf?	–	–	–
How are fish distributions changing with climate?	–	–	–
What is larval fish connectivity between the United States, Cuba and Mexico?	–	–	–
What are locations, seasonality, and status of spawning aggregations?	–	–	–
Connectivity in-shore, off-shore within, and among regions?	–	–	–
What is extent/location of benthic habitat types among regions?	–	–	–
What are differences in fishing effort/landings/mortality among regions-commercial and recreational?	–	–	–
What are the effects of MPAs on fish community structure?	–	–	–

B.2.4 Subject Category: Pelagic Ecology

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the status of Gulf pelagic fish stocks and is it changing (including biodiversity, abundance, production, habitat, movement, & larval dispersion)?	Fisheries independent; Illegal fishing estimates; SeaWatch; REEF; Global Fish Watch	Cuba - CIM-UH, MINAL/CIP & Academics; INAPESCA (Fisheries dependant); CIGOM; Academic (UNAM, ECOSUR, CINVESTAV) US Universities; Tri-national stock assessment workshops	Accessibility & QA/QC of data questionable; Level of uncertainty with existing data; CIGOM

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the population status of marine mammals, turtles, birds, and manatees?	Stock assessements; visual aerial surveys; migratory; acoustics/tagging; nesting; IDs	CINVESTAV, CONABIO, CONAMP, PRONATURA (NGO), Cuba agencies; Gladys Porter, CIGOM	Marine mammal observations from oil and gas permits; CONABIO & CONAMP, MINAL/CIP, CIGOM, Vicente Guzman, CONANP; USGS tagging and genetic data
What are the oceanographic processes driving pelagic ecology (e.g. Loop Current & eddies)?	Baseline physical dynamics (i.e. circulation); monitoring of eddies shed from Loop Current & info on pelagic fauna; acoustics technology on AUVs	CICESE, NOAA (satellite), Universities & others using telemetry; SENAR?, ICIMAR (Cuba)	Physical oceanographic surveys; satellites; remote sensing; HYCOM models (other circulation models)
What is the distribution and movement of sargassum (sea turtles connection to)?	Sargassum origin (geographically), distribution, and abundance	Cuba: CIM, ICIMAR; Mexico: PRONATURA, UABC, CINVESTA, UNAM, CIGOM	Jim Franks (Gulf Research Lab, Alabama); Don Johnson (NRL Stennis)

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are hot spots (open ocean) for pelagic biodiversity?	–	TNC, SeaWatch; Mexico: Lauren Camillo	TNC
Where are important areas for pelagic invertabrates (including distribution, movement, etc.)?	–	–	–
What is the role of the Southern GOM and Caribbean as nursery for pelagics?	–	–	–
What is the overall distribution, role, and balance of lower trophic levels in Southern GOM (bacteria, phyto- and zooplankton) (e.g. carbon dynamics, primary production, microbial loops and HABs)	Microbial loop observations; role balance, etc.; models, CIGOM consortia is already doing	–	–
How does climate affect pelagic ecology and ecosystem?	–	–	–
Deep sea? What is out there? How is surface connected to deep? Connectivity/Interconnectivity	–	–	–

B.2.5 Subject Category: Water Quality

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Socio-economics of current conditions vs. loss of ecosystem health and loss of income (fisheries, tourism)	–	–	–
Ocean acidfication and coral reefs (warming, bleaching)	–	–	–
Upwelling ⟶ productivity; pCO_2 changes ⟶ ocean acidification?	–	–	–
Expand ocean acidification studies across the borders	–	–	–
Identification, via different methods, of contaminants and their uptake and accumulation in living resources	–	–	–
Human activity in watershed shifts to nutrient loading & worsening water quality, hypoxia, HABs, toxins, turbidity – “clear” linkages	–	–	–
Socio-economic conflicts & limitations between ecosystem health and economic growth with “development” money to communities, tourism, cruise ships?	–	–	–
Expansion of oil and gas in Mexico and Cuba and water quality, human communities, socioeconomic balance	–	–	–
What are the environmental conditions in Cuba, status of estuaries, and nearshore environments?	–	–	–
Socio-politico differences and shifts thereof among GOMx countries with regard to business opportunities and development and environmental health	–	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are our priorities that environmenal monitoring needs to address: Physical processes, habitats, organism status?	–	–	–
How pervasive and where hypoxia occurs, especially in southern GoM?	Comb all institutions	Mexico agencies	Very little
HABs/shellfish monitoring for toxins	more geographic coverage	–	USFDA for sources; UJAT "Olga" Pina?
Nutrient inputs, sediments to near coastal	–	–	Studies on Usamacinta-Gujalva River; UNAM; UJAT
Water quality ⟶ ecosystem health ⟶ ecosystem services	–	–	–
Tread carefully with beach condition reports	–	–	–
Sociological disconnect of increased population growth and tourism with degrading water quality	–	–	–
Impervious land ⟶ flooding ⟶ water quality	–	–	–
Expansion of oil and gas in southern GoM with water qaulity, hydrocarbons, spills, pipelines.	Hydrocarbon fingerprint of oil and gas products by industry	–	–
Protocols for water quality testing for uniformity	–	–	–

B.2.6 Subject Category: Geology & Physical Process

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the five variables of interest to determine changes over time to the open ocean Gulf ecosystem?	CO_2, pH, primary productivity, nutrient dynamics, physics, species diversity with time	NSF, NOAA, BOEM, NAS	–
What is the sediment methane and petroleum contribution to the water column budget?	Sea floor gas hydrate and petroleum. Seismic database; carbon isotope, geochemistry	NSF, NOAA, BOEM	Several publications
Dynamics of Loop Current?	Multiple platforms	–	Physical oceanography campaigns
To develop a sufficient sediment distribution map of coastal Gulf of Mexico	Sedimentological and elevation data; Northern GOM studies	USGS, BOEM, States, Mexico, Cuba	LA CPRA map of sediment distribution

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the interchange patterns at the Florida Strait and the Yucatan Channel? What is the total transport? In addition, how the spatially resolved interchange pattern relates to the Loop Current.	High frequency radar maps; Mooring array at Florida Straits	Should be trinational: CONACYT, NSF, Cuba research?	Several years of mooring array at the Yucatan Channel measured by CICESE; A cable (submarine) which crosses from Cuba to Florida and measures total transport
How do the environmental assessment processes in the United States and Mexico compare and how can common standards and practices be most effectively applied in the hydrocarbon producing regions in the GOM?	Legal and policy information from the two nations	BOEM, NOAA, BSEE, Dept. of State, ASEA, Hydrocarbon Commission of Mexico, Ministry of Mexico, Ministry of Energy of Mexico, Foreign Ministry of Mexico	2012 Legal framework for offshore operations of Mexican Oil industry - outdated due to energy reforms of 2013
How does the ventilation process work in the Gulf of Mexico in the intermediate and deep water?	Radiotracers and chemical tracers of intermediate and deep ocean circulation	CONACyT, NSF, BOEM	Oxygen and heat content though limited to
			establish ventilation rates
How do the small-scale processes interact with large scale processes (physical oceanographic processes)?	Fine scale hydrographic and circulation platforms with multiple sensors	NOAA, NSF; Mexico: CONACYT	Existing oceanographic campaigns, numerical model results, mooring observations

Appendix C. Research Questions

C.1. All research questions developed by the Fates and Effects working group, including new data needed to answer the questions, entities that are likely to collect the data, and relevant existing data in the inventory

C.1.1 Subject Category: Corals, Hard Bottoms, & Seagrasses

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
How dependent are coastal communities on coastal and marine ecosystems? Does the adoption of “sustainable” practices increase this relationship?	–	–	–
How do invasives/stressors/pressure affect frequency and intensity of invasions?	–	–	–
Understanding how stressors/pressures affect biodiversity	–	–	–
On what scale should research be conducted to inform decisions?	–	–	–
How does sewage treatment practices affect coral, hard bottom, and seagrass?	–	–	–
What are the best restoration strategies to increase coral, hard bottom, and seagrass?	–	–	–
How do you define vulnerability of these habitats & quantify it for targeted conservation?	–	–	–
What are the relevant inputs (nutrients & pollutants)? How do we quantify & understand their fate?	–	–	–
Strategies for MPA & corridors for coral, hard bottom, and seagrass preservation	–	–	–
Get info to local scientists w/r/t government agencies/International agreements & relationships	–	–	–
What is the current distribution of seagrass, hardbottom, and coral throughout the GOM?	Lots, LIDAR, Multi-beam, side scan, visual survey, Seems to be less data in Mexico EEZ based on limited participation in this group	NOAA, USGS, Mexican counterparts, Universities	–
How do we scale models to understand local impacts, and inversely, to understand how local changes affect regional ecosystems?	Local mechanistic process studies, model parameterization for local scales?	–	–
How to best site artificial reefs based on environmental & social conditions?	Oceanography, water quality, social indicators (fishing, tourism), fish counts, all should use BACI tests & Active Adaptive Management	–	–

How do we accurately quantify cumulative human impacts throughout the GOM?	Atmospheric inputs, terrestrial inputs, and marine inputs, and benthic/geologic inputs	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
How do these cumulative impacts affect these habitats and associated fisheries?	Long-term & transect lines from highly impacted to pristine sites- long-term spatially explicit fish data-management & fishing practices	–	–
How do these changes in habitat & fisheries affect adjacent socioeconomics?	Local-scale data on employment, income, ecosystem services, & human well-being	–	–
How should we apply informatics to improve our understanding, characterization, & management of GOM?	Single integrated database & gap analysis (super computers)	–	–
How do we integrate across Ecosytem components & spatial/temporal scales?	Single integrated database & gap analysis (super computers)	–	–
What are the impacts of acidification on the coral, hard bottom, and seagrass & how does that vary due to environmental condition, habitat characteristics?	High temporal & spatial long-term data on the carbon cycle; adaptation-based data on organism response-impacts on all life staqges, especially juvenile, embryonic, larval, & reproductive stages	–	–
What are the impacts of coastal communities on coral, hard bottom, and seagrass? How do the relative adoption of sustainability practices affect these impacts?	Data on local governance, ordinances, and practices (or lack thereof); perception of local communities on coral, hard bottom, seagrass health; data on enforcement	–	–
Ideas to incorporate humans as part of the ecosystem not external to the system	–	–	–
More coral work to discriminate from anthropogenic impacts and natural variability	–	–	–
How can we ID the most vulnerable areas to climate change and be proactive in preparing?	–	–	–
How can we improve enforcement of environmental regulations w/r/t cruiseships?	–	–	–
Small scall connectivity between mangrove, seagrass, and coral reefs for management decisions	–	–	–
Understand environmental conditions that promote coral disease in GOM	–	–	–
Impacts of overfishing effects on coral reefs and other systems	–	–	–

C.1.2 Subject Category: Infauna/Meiofauna

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Is there a Benthic Index of Biotic Integrity that works in the northern Gulf?	Information on species sensitivity	BOEM, Academic Institutions	Databases with info on fauna and pollutants. Toxicity data?
Benthic Foraminfera (BF) sensitivity as recorders of oil spill events	Large databases of B.F. in different environments. Lab experiments	Academic institutions	BF collections in oil impacted areas
Evaluate the effect of environmental variables versus the effect of pollutants	Long-time series	Academic institutions	Time series databases
How to assess damages without a baseline	Benthic samples in unaffected areas and/or study cores of “pristine times”	Academia, Government	DGOMB
Why do we care about infaunal changes?	Socioeconomic surveys; benthic connectivity to other habitats	NGOs and others	–
Which ar ethe better organisms to evaluate oil impact? More sensitive.	Experiments	Academic institutions related with these topics	Articles, reports
What can bacteria tell us about oil sediment depuration?	Metagenomic and epigenomic of microorganisms from sediments	Academic institutions, CIGOM, CINVESTAV	–
Trophic relationships of fishes that feed on meiofauna	Sampling meiofauna and trophic analysis with isotopic relationship	Academic institutions	–
Concentration of pollutants (PAHs, PCBs, pesticides) in both hosts and parasites	Determining the concentrations of pollutants on both hosts and parasites	Academic institutions; PEMEX; Oil companies	–
What communication of inputs/stresses exist between compartments (benthic, demersal, pelagic) and laterally between regions?	Transport of tracers; concentrations of markers for contaminants	–	–
What are the impacts of the oil platforms (cuttings, debris, sewage) on infauna/meiofauna around them?	Surveys/collections of infauna/meiofauna and sediments	PEMEX and other oil companies; Academic institutions	–

C.1.3 Subject Category: Demersal Fish

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the biodiversity of deep sea fishes in GOM (3600–7200 m)	Deep fish communities - biodiversity, quantity, parasites? Load/prevalance/diversity; Need alternate gear to sample hard bottom	CINVESTAV; UNAM; CICESE	Data for 200-1200m
What is the environmental health of the entire GOM, crossing boundaries?	Connectivity; toxicology; natural toxins & diseases; anthropogenic contaminant loads; nutrients; physical/chemical data	All agencies in MX, US, and Cuba; Universities of the Gulf States	–
What is the period of recovery after oil/natural impact following disturbance (oil, hurricane, etc.)?	Microbial data; Biodiversity across food webs (functional, taxon, genetic); Resilience of organism or community vs ecosystem level; Ecosystem recovery; Clearance rates of pollutants (PAH, PCBs)	Academia, mostly research Universities	National Institute of Petroleum (IMP)
What are the long-term chronic issues affecting coastal zones & ecosystems…pesticides, processed water?	Water quality data databases; Sediment quality; Benthic organisms/changes in biodiversity; Human community health	Universities; Federal Research Agencies	–
Implementation of environmental releases policy and regulation	Policy and regs exist but poorly implemented along the MX coast	–	–
How are fisheries (e.g., tuna, shrimp) activities impacting the biological communities? Top-down pressure?	Long-term monitoring databasess on fish captures; Monitoring is intermittant; Funding for short projects	Data is collected but not shared; INAPESCA; CONAPESCA	–
Improve communication and education of fisheries impacts and issues with fisherman - extension work	Catch data for demersal fishes; Fishery independent data needed	–	–
What solutions to overfishing could be assessed? Mariculture, Aquaculture	Experimental mariculture; Life cycles of fishes; Energy requirements; Nutrition; Aquatic health	CINVESTAV - Mérida; ICML-UNAM; UNAM-SISAL; EPOMEX-USC; INAPESCA	–
Standardization and harmonization of methodology for toxicological studies	“All data” methods across boundaries	CIGOM - All over Mexico	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What is the prevalance, distribution, and risk associated with natural toxins in coastal fisheries (e.g., Ciguatera, Brevatoxins…)?	Cross-boundary collaborations; Food web dynamics; spatial and temporal toxin data impacts and effects; Human health impacts	In Mexico: Monitoring ministry of Health Campeche/Yucatan; Universities; COPRISCAM; CINVESTAV; NAVY is supposed to have surveillance; water sampling	–
What is the effect of marine debris and microplastics on demersal fishes in the GOM?	What are the impacts/effects? Secondary effects/exposure to pollutants; Chemical degradation of plastics; Education/Outreach	UNAM; Need collaborative efforts	–
What are the effects of PPCPs/hormones/pharmaceuticals/cosmetics/illegal drugs, etc. in coastal waters on demersal fish?	Physical, transport processes in GOMx	–	–
How are seasonal fisheries regulations different between countries and how does this affect populations/stocks?	Need international communication; Fisheries in one region may not be protected in another region compared to another, so there may be impacts on stocks/management of species	Dept. of Fisheries & Agriculture; NOAA; USFWS	Zoning/Regs
What are the impacts of invasive species in the GOMx? What are they? Where are they? How are they connected? Impacts on native populations?	Damselfish - oil platform habitat; Lionfish; Tiger shrimp (Penaes monodon); Phytoplankton-bacteria-pathogens-Vibrio; Sponges; Algae; Enumeration; Ballast water/species movement/diseases that they bring	EADY; CICY-Q. Roo; CINESTAV; ECOSUR; UNAM-ICML	–
What is the connection between coastal and deepwater fisheries - migration, exposure, behavioral effects, bioaccumulation?	–	–	–
What are the "-omics" changes between natural seeps compared to unexposed communities and compared to direct exposure? "Global expression" - metabolomics, proteomics, transcriptomics?	–	–	–
What are the resultant mechanisms employed by fish to deal with chemical exposure?	–	–	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the effects of fisheries gear (e.g., trawls) on seafloor habitat and what can be done? New development of fishing strategies.	Gear selection	PESCA - Federal; NOAA - Federal; SEAGRANT	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Human health impacts of contaminants/toxins in coastal communities and imports/exports?	Identification of natural or anthropogenic contaminants - what are their origins? Repetition/consistency; Sampling, long-term monitoring	Federal (CDC; FDA; EPA) Mexico (Institutiion of Fisheries); Academic (Tulane; Univerity of Maryland); NIH; SEMARNAT; Cuba (Ministry of Health)	–
What are the drivers of invasive species? Why are they moving to new areas?	Lots of sampling; multidisciplinary sampling; Biogeographical food webs for bigger picture of an ecosystem; Reward-based removal, buy-back incentive	All agencies in MX, US, and Cuba	–
Environmental impacts of mariculture/aquaculture applications	Monitoring; water quality; fish quality/health	–	–

C.1.4 Subject Category: Pelagic Ecology

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Life stages/population/physical/chemical connectivity across GOM ecosystems	Genetic data; Isotopes; Megafauna tagging/tracking; Mesoscale oceanographic structure	NOAA; Research Centers (e.g. CINVESTAV, UNAM); General literature	Various populaton studies; Circulation models
Benthic habitat mapping	PEMEX data; remote sensing; direct sampling	NOAA; Research Centers in MX & Cuba	PEMEX data; other oil companies and industry
Cross-national fisheries management (e.g., tuna, shrimp, sharks, snapper, swordfish)	Population structure (space & time); Catch statistics; By-catch statistics; Impacts of pollutants including atmospheric	NOAA; INAPESCA; CINVESTAV; NMFS; CICIMAR-IPN; EPOMEX-USCDM	INAPESCA data; OBIS/GBIF databases; Studies of fish populatons; by-catch records
Common science-based regulatory framework for environmental management and response to human impacts	Agency-to-agency information transfer	NOAA; NMFS; USCG; SEMARNAT; ASEA; CNH (Comisión nacional de hydrocarburos); SRE	National regulatory frameworks
Effects of pollutant mixtures on pelagic organisms - Also, nutrient and climate change CO_2 (field and experimental data - bioassays)	Coordinated sampling of water column, sediments and organisms; Coordinate work for experiments	Independent investigators; Academic institutions that already work in this area; ASEA	Scientific papers, reviews, reports
How to compile all the tagging/tracking information that we already have on the pelagic organisms?	More tagging systems and findings; Maps with distributions	–	–
What is the stage of development of the organisms and which area do they cover during each stage?	–	–	–
How does sargassum afffect biodiversity and productivity?	–	–	–
What is the role of DOM in nutrient and C-cycling and food web dynamics? Community structure & function across Gulf ecosystems	Pollutants/surveys	NOAA; NMFS; INAPESCA; CONABIO;	–

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
		CINVESTAV; IPN; CICIMAR	
How does physical connectivity compare with biological connectivty?	–	–	–

C.1.5 Subject Category: Water Quality

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the main sources of stressors on water quality in the SGOM and north of the Caribbean Sea?	Collect information from private sources; Do gap analysis and identify useful information	Pork growing industry; CFE; CONAGUA; INEGI; PRFEPA; SEMARNAT	Review the information of the inventory & identify reports from private industry; SEMARNAT
What are the linkages between air quality and water quality?	Meterological data; air quality data; models to analyze data; centralized information monitoring programs	INECC; Universities	INECC
How we can use models of interactions - atmosphere, ocean and land	Model development for air quality and water quality	Universities; INEGI, PEMEX; SEMARNAT	Universities; INEGI, PEMEX; SEMARNAT
What are the impacts of fracking technology on water quality?	Analysis of the American databases; Understand how fracking may impact Mexican industry	IPN; IMP	IPN, IMP
How can we calibrate methodologies betweeen researchers from all over the GOM? How could we develop national standards based on international best practices that involve calibration of different methodologies and different research focuses?	Need to develop National standards based on international best practices; QA/QC; Oil fingerprints; Best practices	Universities; CIGOM; GESAMP; Use National Academy of Sciences to inform and locate experts	Universities; GESAMP; NAS; CIGOM; CICESE, CIVESTAV
What are the impacts of CO_2 increases and acidification changes in the coastal zone/ocean?	Mooring system to collect information on pH, temperature, salinity, carbonate shells (molluscs, forminifera); Ferry boxes	Universities; INECC; Navy; Academic Institutions	Need to develop new inventories

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
How does changing freshwater inflow affect water quality? (Mexican input agreement)	Understand the impact on estuarine species of the modification of the freshwater discharge; relationships with human activiities such as damming	Universities; IMTA; CONAGUA	CONAGUA database
What are the impacts of nutrient inputs and how will climate change affect those impacts?	From the rivers, sewage, agro-industry	CONAGUA; Universities; IMTA	CONAGUA database

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
What are the impacts of transport between different compartments & ground water discharge to the ocean?	–	CINVESTAV; Academic institutions in the region; NAVY marine research labs	CINVESTAV has data on ground water

C.1.6 Subject Category: Geology & Physical Processes

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
How does oil spread and behave under various conditions and scenarios in the Gulf of Mexico?	Controlled field experiement with real oil	ASEA (permits); Academic institutions; Industry (oil companies)	Lagrangian data; Modeling: atmosphere and ocean; Moorings; Science from Deepwater Horizon
What drives the Campeche Gyre?	High resolution array of current meters and and floats	CICESE; CCA-UNAM	Lagrangian data; Mooring data; Hydrographic data; Model data
How do Loop Current eddies dissipate? Evolve?	Targeted observations with hydrographic data and gliders data	Joint effort US - Mexico; CICESE - FSFLAS; Texas A&M; other institutions	Mooring (BOEM); Lagrangian data; Past eddies, physical data
How do MPAs around the GOM region connect with one another?	Biology data (genetics, larval data); Lagrangian data; Moorings around MPAs and on shelf	Joint effort US - Mexico; NOAA; Academic institutions (UNAM, RSFLAS, CICESE…)	Altimetry; Lagrangian data; existing moorings
What is the shape of the kinetic energy spectrum?	Drifter data deployed appropriately; Repeated ADCP sections	CICESE; RSFLAS; TEXAS A&M; Academic institutions; oil industry	None!!
What is the long-shelf and cross-shelf circulation variablility in the southern GOM?	Mooring arrays with current profilers in real time	CCA-UNAM; CICESE; CICATA; University of Vera Cruz; Sisal	Existing moorings and current profilers; Regional model; Meteorological model

Proposed Research Question	Necessary New Data?	Entities that Might Collect the Data	Existing Relevant Data in the Inventory
Are there signals in the Caribbean Sea that act as precursors to Loop Current eddy shedding?	More RAFOS data; Mooring data	CICESE; TAMU; BOEM; NAS; CCA-UNAM, ETC.	Opportunities for marvelous joint project that will allow use of current and historic data!
What is the role of LCS in the vertial flux of carbon? What is the sustainability and variability of those structures?	Altimetry in high resolution; Lagrangian data	RSMAS; NOAA; IMTA	Models; Altimetry
What is the effect of the geomorphology on how pollutants affect benthic populations?	High resolution bathymetry; Seafloor consistency sampling (sediment properties and pollutants); Organisms; Wide area of sampling repeated	Oil companies should and academic institutions (UNAM; CICESE; CINVESTAV)	All high-resolution bathymetry from PEMEX or other oil companies
Have better atmosphere models to understand heat, mass, and momentum fluxes	Winds and fluxes measurements	CCA-UNAM; CICESE; IMTA	Data from buoys in northern Gulf
What is the history of ecological effects due to natural and anthropogenic sources in the benthos?	Sediment cores in a variety of environments	Academic institutions	Bathymetry from oil industry
What is the distribution of natural oil seeps in the SGOM?	High resolution bathymentry; ROVs	Oil companies; Academic institutions	Oil industry data
What is the concentration of micro- and macro-plastics in the water column and in the sediments?	Water samples and sediment cores	Oil companies; Academic institutions	Databases from UNAM and IPN
Paleotsunamis?	Sediment cores	Oil companies; Academic institutions	Databases from UNAM and IPN
What are the transport processes of oil in the vertical water column with and without dispersants? (Needed to be able to run mesocosms and bioassays with oil exposure)	Laboratory experiments	Academic institutions	???
Are there mass washing (mudflow) events in the SGOM (e.g., Grijalva-Usamacinta Rivers)?	High resolution bathymentry; Sub-bottom profiling data	Oil and gas industry	Oil and gas industry; Map what is available
How will vertical fluxes of carbon and oxygen change in the long term,?	–	–	–
Physical and biogeochemical modeling intercomparison	–	–	–

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).