

Scenarios and Responses to Future Deep Oil Spills

Steven A. Murawski • Cameron H. Ainsworth
Sherryl Gilbert • David J. Hollander
Claire B. Paris • Michael Schlüter
Dana L. Wetzel
Editors

Scenarios and Responses to Future Deep Oil Spills

Fighting the Next War

 Springer

Editors

Steven A. Murawski
College of Marine Science
University of South Florida
St. Petersburg, FL, USA

Cameron H. Ainsworth
College of Marine Science
University of South Florida
St. Petersburg, FL, USA

Sherryl Gilbert
College of Marine Science
University of South Florida
St. Petersburg, FL, USA

David J. Hollander
College of Marine Science
University of South Florida
St. Petersburg, FL, USA

Claire B. Paris
Rosenstiel School of Marine
& Atmospheric Science
University of Miami
Miami, FL, USA

Michael Schlüter
Hamburg University of Technology
Hamburg, Germany

Dana L. Wetzel
Mote Marine Laboratory
Sarasota, FL, USA

ISBN 978-3-030-12962-0 ISBN 978-3-030-12963-7 (eBook)
<https://doi.org/10.1007/978-3-030-12963-7>

© Springer Nature Switzerland AG 2020

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword and Dedication

Global production of liquid fossil hydrocarbons was 34 billion barrels in 2017,¹ with production increasing an average 1.1% per year during the preceding decade (BP 2018). Maintaining and increasing production now involves expansion into “frontier” areas including nontraditional terrestrial and aquatic realms. Marine oil exploration and production has advanced steadily offshore since its inception in the Gulf of Mexico in the 1930s (Murawski et al. 2020). For the first time, in 2017, more crude oil was generated from ultra-deep (>1 mile deep) waters of the Gulf of Mexico than in shallower waters (Murawski et al. 2020). This trend to deeper production is occurring in all major marine oil provinces of the world.

The *Deepwater Horizon* (DWH) oil spill was the world’s first ultra-deep well blowout, but likely not the last. Deep well fields in the Gulf of Mexico now extend to depths nearly twice that of DWH. Ultra-deep wells present unique technical and environmental challenges. Because of the immense depths and pressures, ultra-deep wells are more complex, risk-prone, and expensive to construct and maintain as compared to equivalent shallower facilities. Notwithstanding these issues, and depending on the price of oil, the volumes of oil produced at ultra-deep wells can be enormously profitable, yielding many times the production rates of those inshore (Murawski et al. 2020).

The purposes of this book are to synthesize relevant science related to potential oil spills in frontier marine domains and to project the fate and impacts of simulated ultra-deep blowouts. No two spills are alike, and the conditions of the next ultra-deep well blowout will be different from both the DWH and the shallower Ixtoc 1 experiences. Prior to DWH, response planning for marine oil spills primarily assumed a scenario similar to the last major marine oil spill in the United States – the *Exxon Valdez* tanker accident in Alaska. Thus, responders were generally unprepared for the scenario of a deep and unconstrained well blowout in terms of infrastructure and basic science to reasonably inform the use of novel response measures.

¹One stock tank barrel = 42 gallons = 158 l; includes crude oil, shale oil, oil sands, and NGLs (natural gas liquids, the liquid content of natural gas where this is recovered separately)

Rather than concentrating on unresolved issues remaining post-DWH, we simulate spills in the Gulf of Mexico regions where oil and gas exploration and production may in the future occur (e.g., deep water in the eastern, western, and southern Gulf). Likewise, we consider spills in other frontier areas (e.g., off West Africa and in the Arctic). These location-specific simulations of oil fates and their relative impacts on ecological communities and economic activities (fishing) differ from the DWH scenario in fundamental and important ways. Under alternative conditions of oil type, gas/oil ratios, water depth, etc., oil fate and effects will vary still. The point of these simulations, and the importance of closing existing research gaps, is that conditions will be different and therefore response strategies must be nimble to effectively deal with the next ultra-deep oil well blowout, pipeline rupture, tanker-platform collision, industrial sabotage incident, or whatever the scenario may be. Assuming a replay of DWH will surely repeat the cycle of anticipating the next “war” by preparing for the last. Having a fuller repertoire of science applicable to a wide array of idiosyncratic conditions is the key to anticipating and effectively responding to the next spill of significance.

Despite the nearly \$1 billion spent on relevant science since the DWH accident, there remain a number of critical science gaps that preclude consensus on best options to prevent or at least more efficiently respond to the next major spill. A short list of recommended science priorities and policy options is discussed. Nevertheless, there will always be uncertainty concerning the physics, chemistry, geology, and ecology associated with particular ultra-deep well blowouts. Perhaps as important to closing the science gaps that remain, identifying the attributes of locations that are too risk-prone or too ecologically or economically sensitive to permit oil exploration and production should be a priority. Should all frontier areas where oil and gas resources are technically feasible to recover be produced? This is the domain of policy, and informing the consequences of policy choices is the province of environmental science as characterized in the chapters that follow.

Much of the science synthesized in this volume was a result of support and funding from the Gulf of Mexico Research Initiative (GoMRI). The GoMRI enterprise was funded through a \$500 million grant established in the wake of the DWH accident. Many of the authors and all of the coeditors of this book are members of the Center for Integrated Modeling and Analysis of Gulf Ecosystems (C-IMAGE), one of the several research centers supported by GoMRI. Authorship of this volume also includes contributions by members of other GoMRI-funded centers, as well as those from government, academic, and private research organizations. We are deeply grateful to the leadership, staff, and research board of GoMRI for supporting these efforts to better understand the science of deep oil spills and to synthesize that science into actionable alternatives to inform government and industry.

This volume is dedicated to the 11 men who lost their lives aboard the MODU (Mobile Offshore Drilling Unit) *Deepwater Horizon* on April 20, 2010:

Jason C. Anderson, age 35
Aaron Dale Burkeen, age 37
Donald Clark, age 49
Stephen Ray Curtis, age 39
Gordon L. Jones, age 28
Roy Wyatt Kemp, age 27
Karl D. Kleppinger, Jr., age 38
Keith Blair Manuel, age 56
Dewey A. Revette, age 48
Shane M. Roshto, age 22
Adam Weise, age 24

The work described herein has been undertaken with the goal of preventing such accidents from ever happening again and reducing risks to the environment and people should they reoccur. In this way, we honor those whose lives were lost that they helped stimulate national and international action to make marine oil and gas production safer. The families of those who lost their lives in the *Deepwater Horizon* accident expect and deserve nothing less.

St. Petersburg, FL, USA
St. Petersburg, FL, USA
St. Petersburg, FL, USA
St. Petersburg, FL, USA
Miami, FL, USA
Hamburg, Germany
Sarasota, FL, USA

Steven A. Murawski
Cameron H. Ainsworth
Sherryl Gilbert
David J. Hollander
Claire B. Paris
Michael Schlüter
Dana L. Wetzel

References

- BP (2018) BP Statistical Review of World Energy. 67th edn 25 pp. <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf>
- Murawski SA, Hollander DJ, Gilbert S, Gracia A (2020) Deep-water oil and gas production in the Gulf of Mexico, and related global trends (Chap. 2). In: Murawski SA, Ainsworth C, Gilbert S, Hollander D, Paris CB, Schlüter M, Wetzel D (eds) Scenarios and responses to future Deep Oil Spills – fighting the next war. Springer, Cham



The C-IMAGE research consortium, January 2014, Mobile, Alabama

Contents

Part I Overview

- 1 Introduction to the Volume** 4
Steven A. Murawski, Cameron H. Ainsworth,
Sherryl Gilbert, David J. Hollander, Claire B. Paris,
Michael Schlüter, and Dana L. Wetzel
- 2 Deepwater Oil and Gas Production in the Gulf of Mexico
and Related Global Trends** 16
Steven A. Murawski, David J. Hollander, Sherryl Gilbert,
and Adolfo Gracia
- 3 Spilled Oil Composition and the Natural Carbon
Cycle: The True Drivers of Environmental Fate
and Effects of Oil Spills** 33
Edward B. Overton, Dana L. Wetzel, Jeffrey K. Wickliffe,
and Puspa L. Adhikari

Part II Geological, Chemical, Ecological and Physical Oceanographic Settings and Baselines for Deep Oil Spills in the Gulf of Mexico

- 4 An Overview of the Geologic Origins of Hydrocarbons
and Production Trends in the Gulf of Mexico** 60
Stanley D. Locker and Albert C. Hine
- 5 Gulf of Mexico (GoM) Bottom Sediments and Depositional
Processes: A Baseline for Future Oil Spills** 75
Gregg R. Brooks, Rebekka A. Larson, Patrick T. Schwing,
Arne R. Diercks, Maickel Armenteros, Misael Diaz-Asencio,
Adrian Martínez-Suárez, Joan-Albert Sanchez-Cabeza,
Ana C. Ruiz-Fernandez, Juan Carlos Herguera,
Libia H. Pérez-Bernal, and David J. Hollander

6	Benthic Faunal Baselines in the Gulf of Mexico: A Precursor to Evaluate Future Impacts	96
	Patrick T. Schwing, Paul A. Montagna, Maria Luisa Machain-Castillo, Elva Escobar-Briones, and Melissa Rohal	
7	Linking Abiotic Variables with Macrofaunal and Meiofaunal Abundance and Community Structure Patterns on the Gulf of Mexico Continental Slope	109
	Paul A. Montagna, Jeffrey G. Baguley, Gilbert T. Rowe, and Terry L. Wade	
8	The Asphalt Ecosystem of the Southern Gulf of Mexico: Abysal Habitats Across Space and Time	132
	Ian R. MacDonald, Adriana Gaytan-Caballero, and Elva Escobar-Briones	
9	Geochemical and Faunal Characterization in the Sediments off the Cuban North and Northwest Coast	147
	Maickel Armenteros, Patrick T. Schwing, Rebekka A. Larson, Misael Díaz-Asencio, Adrian Martínez-Suárez, Raúl Fernández-Garcés, David J. Hollander, and Gregg R. Brooks	
10	Mapping Isotopic and Dissolved Organic Matter Baselines in Waters and Sediments of the Gulf of Mexico	160
	Jeffrey P. Chanton, Aprami Jaggi, Jagoš R. Radović, Brad E. Rosenheim, Brett D. Walker, Stephen R. Larter, Kelsey Rogers, Samantha Bosman, and Thomas B. P. Oldenburg	
11	Toward a Predictive Understanding of the Benthic Microbial Community Response to Oiling on the Northern Gulf of Mexico Coast	182
	Joel E. Kostka, Will A. Overholt, Luis M. Rodriguez-R, Markus Huettel, and Kostas Konstantinidis	
12	Combining Isoscapes with Tissue-Specific Isotope Records to Recreate the Geographic Histories of Fish	203
	Ernst B. Peebles and David J. Hollander	
13	The Utility of Stable and Radioisotopes in Fish Tissues as Biogeochemical Tracers of Marine Oil Spill Food Web Effects . . .	219
	William F. Patterson III, Jeffery P. Chanton, David J. Hollander, Ethan A. Goddard, Beverly K. Barnett, and Joseph H. Tarnecki	
14	Modernizing Protocols for Aquatic Toxicity Testing of Oil and Dispersant	239
	Carys L. Mitchelmore, Robert J. Griffitt, Gina M. Coelho, and Dana L. Wetzel	

15 Polycyclic Aromatic Hydrocarbon Baselines in Gulf of Mexico Fishes 253
 Erin L. Pulster, Adolfo Gracia, Susan M. Snyder, Isabel C. Romero, Brigid Carr, Gerardo Toro-Farmer, and Steven A. Murawski

16 Case Study: Using a Combined Laboratory, Field, and Modeling Approach to Assess Oil Spill Impacts 272
 Sandy Raimondo, Jill A. Awkerman, Susan Yee, and Mace G. Barron

Part III Simulations of Future Deep Spills

17 Testing the Effect of MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) Events in Benthic Microcosms. 288
 Edwin M. Foekema, Justine S. van Eenennaam, David J. Hollander, Alette M. Langenhoff, Thomas B. P. Oldenburg, Jagoš R. Radović, Melissa Rohal, Isabel C. Romero, Patrick T. Schwing, and Albertinka J. Murk

18 Physical Processes Influencing the Sedimentation and Lateral Transport of MOSSFA in the NE Gulf of Mexico. 300
 Kendra L. Daly, Ana C. Vaz, and Claire B. Paris

19 Simulating Deep Oil Spills Beyond the Gulf of Mexico. 315
 Claire B. Paris, Ana C. Vaz, Igal Berenshtein, Natalie Perlin, Robin Faillettaz, Zachary M. Aman, and Steven A. Murawski

Part IV Comparisons of Likely Impacts from Simulated Spills

20 Comparison of the Spatial Extent, Impacts to Shorelines, and Ecosystem and Four-Dimensional Characteristics of Simulated Oil Spills 340
 Igal Berenshtein, Natalie Perlin, Cameron H. Ainsworth, Joel G. Ortega-Ortiz, Ana C. Vaz, and Claire B. Paris

21 A Predictive Strategy for Mapping Locations Where Future MOSSFA Events Are Expected. 355
 Albertinka J. Murk, David J. Hollander, Shuangling Chen, Chuanmin Hu, Yongxue Liu, Sophie M. Vonk, Patrick T. Schwing, Sherryl Gilbert, and Edwin M. Foekema

22 Connectivity of the Gulf of Mexico Continental Shelf Fish Populations and Implications of Simulated Oil Spills 369
 Claire B. Paris, Steven A. Murawski, Maria Josefina Olascoaga, Ana C. Vaz, Igal Berenshtein, Philippe Miron, and Francisco Javier Beron-Vera

23 Evaluating the Effectiveness of Fishery Closures for Deep Oil Spills Using a Four-Dimensional Model 390
 Igal Berenshtein, Natalie Perlin, Steven A. Murawski, Samatha B. Joye, and Claire B. Paris

24 As Gulf Oil Extraction Goes Deeper, Who Is at Risk? Community Structure, Distribution, and Connectivity of the Deep-Pelagic Fauna 403
 Tracey T. Sutton, Tamara Frank, Heather Judkins, and Isabel C. Romero

25 Evaluating Impacts of Deep Oil Spills on Oceanic Marine Mammals 419
 Kaitlin E. Frasier

26 Comparative Environmental Sensitivity of Offshore Gulf of Mexico Waters Potentially Impacted by Ultra-Deep Oil Well Blowouts. 443
 Emily Chancellor, Steven A. Murawski, Claire B. Paris, Larry Perruso, and Natalie Perlin

Part V Preparing for and Responding to the Next Deepwater Spill

27 Preparing for the Inevitable: Ecological and Indigenous Community Impacts of Oil Spill-Related Mortality in the United States’ Arctic Marine Ecosystem 470
 Paul M. Suprenand, Carie Hoover, Cameron H. Ainsworth, Lindsey N. Dornberger, and Chris J. Johnson

28 Summary of Contemporary Research on the Use of Chemical Dispersants for Deep-Sea Oil Spills 494
 Steven A. Murawski, Michael Schlüter, Claire B. Paris, and Zachary M. Aman

29 Perspectives on Research, Technology, Policy, and Human Resources for Improved Management of Ultra-Deep Oil and Gas Resources and Responses to Oil Spills. 513
 Steven A. Murawski

Index. 531