Oil in the Environment

Legacies and Lessons of the *Exxon Valdez* Oil Spill

What light does nearly 25 years of scientific study of the *Exxon Valdez* oil spill shed on the fate and effects of a spill? How can the results help in assessing future spills? How can ecological risks be assessed and quantified?

In this, the first book on the effects of *Exxon Valdez* in 15 years, scientists directly involved in studying the spill provide a comprehensive perspective on, and synthesis of, scientific information on long-term spill effects. The coverage is multidisciplinary, with chapters discussing a range of issues including effects on biota; successes and failures of postspill studies and techniques; and areas of continuing disagreement. An even-handed and critical examination of more than two decades of scientific study, this is an invaluable guide for studying future oil spills and, more broadly, for unraveling the consequences of any large environmental disruption.

A full bibliography of related literature is available online at www.cambridge.org/9781107027176.

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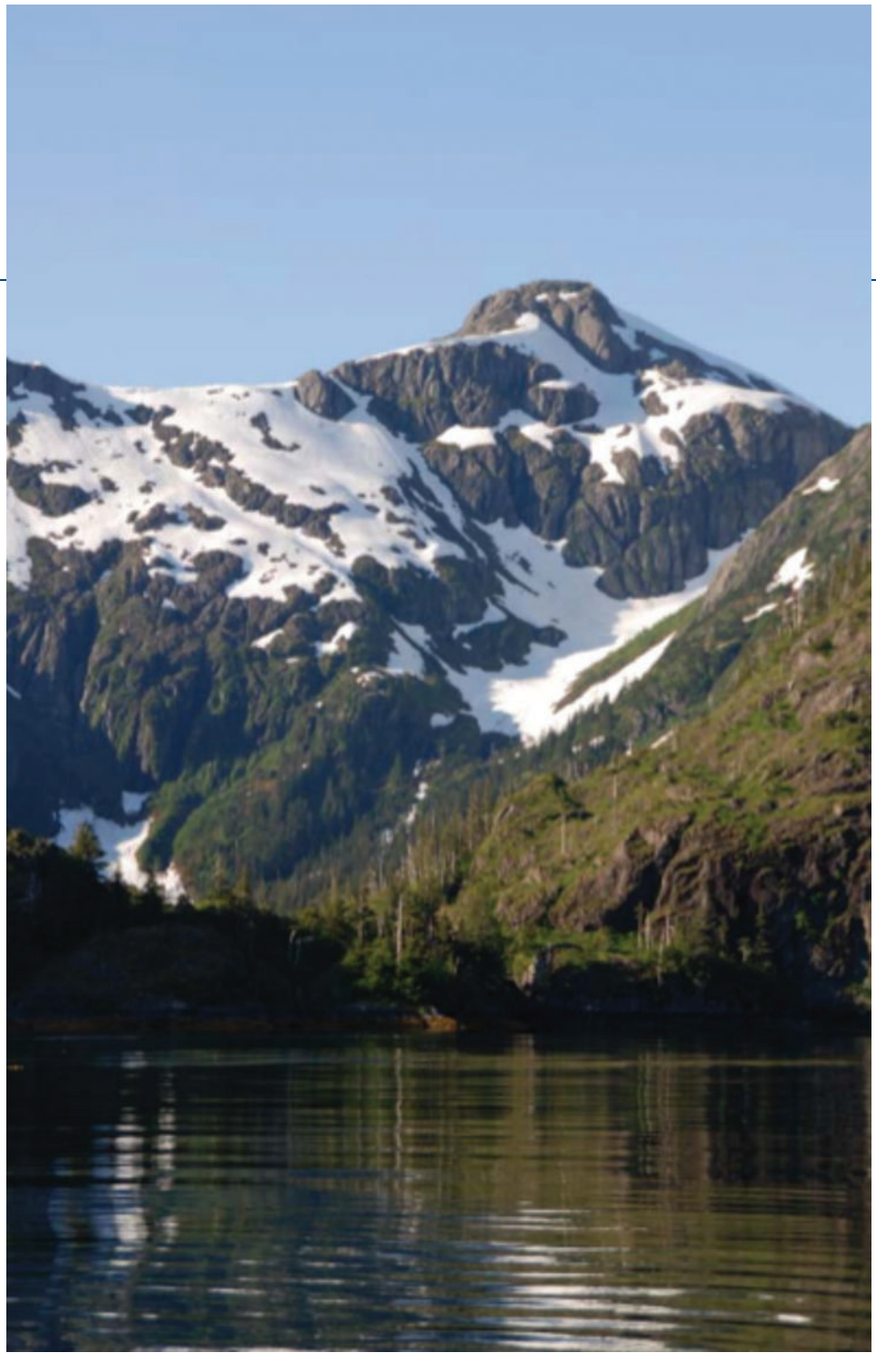

Frontispiece. Southeastern Herring Bay, Knight Island, Prince William Sound, Alaska, July 2008. Herring Bay was one of the areas most heavily oiled by the *Exxon Valdez* oil spill in 1989. Photo: John A. Wiens.

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Edited by

John A. Wiens

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and THE UNIVERSITY OF WESTERN AUSTRALIA, PERTH

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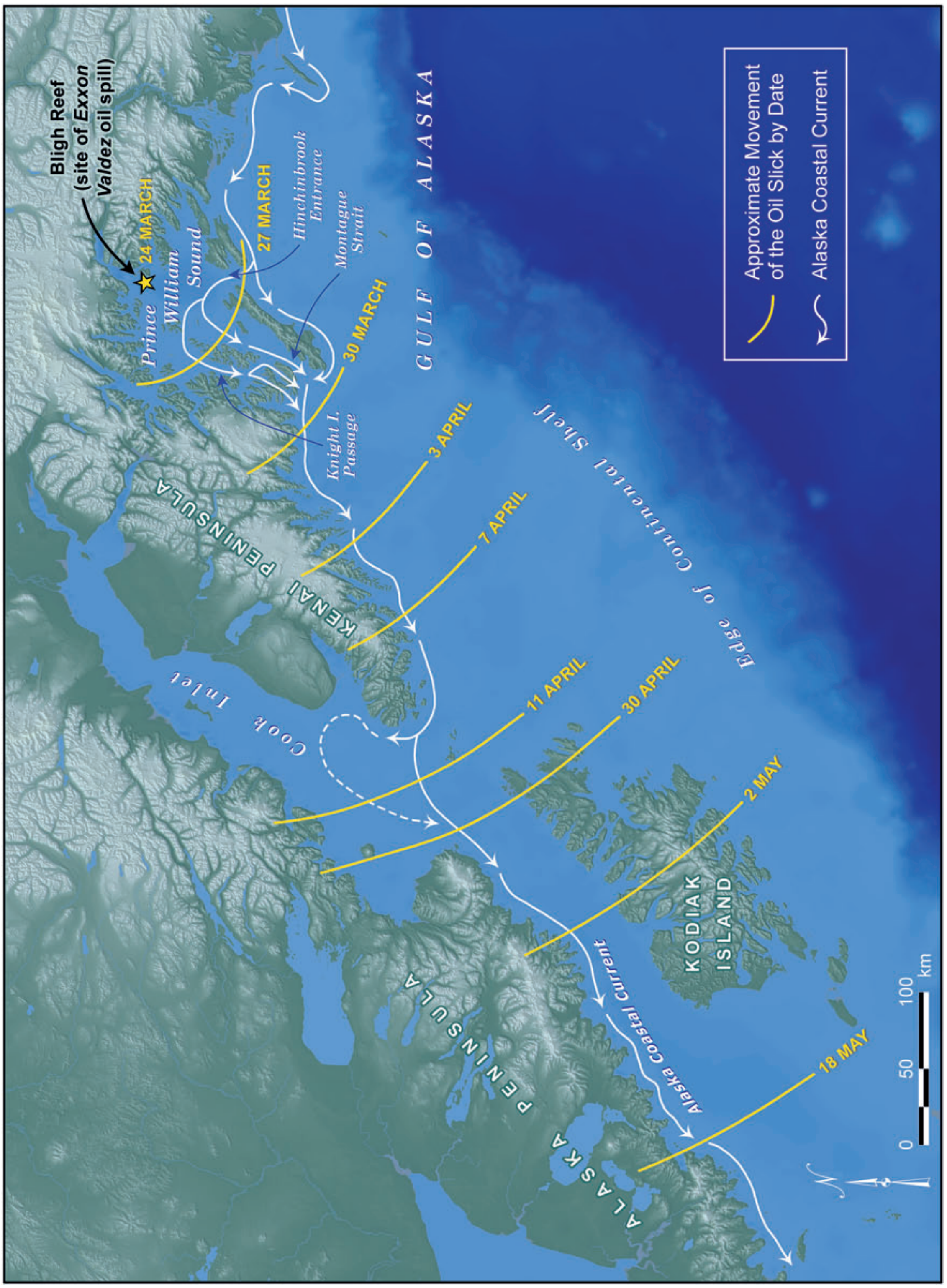
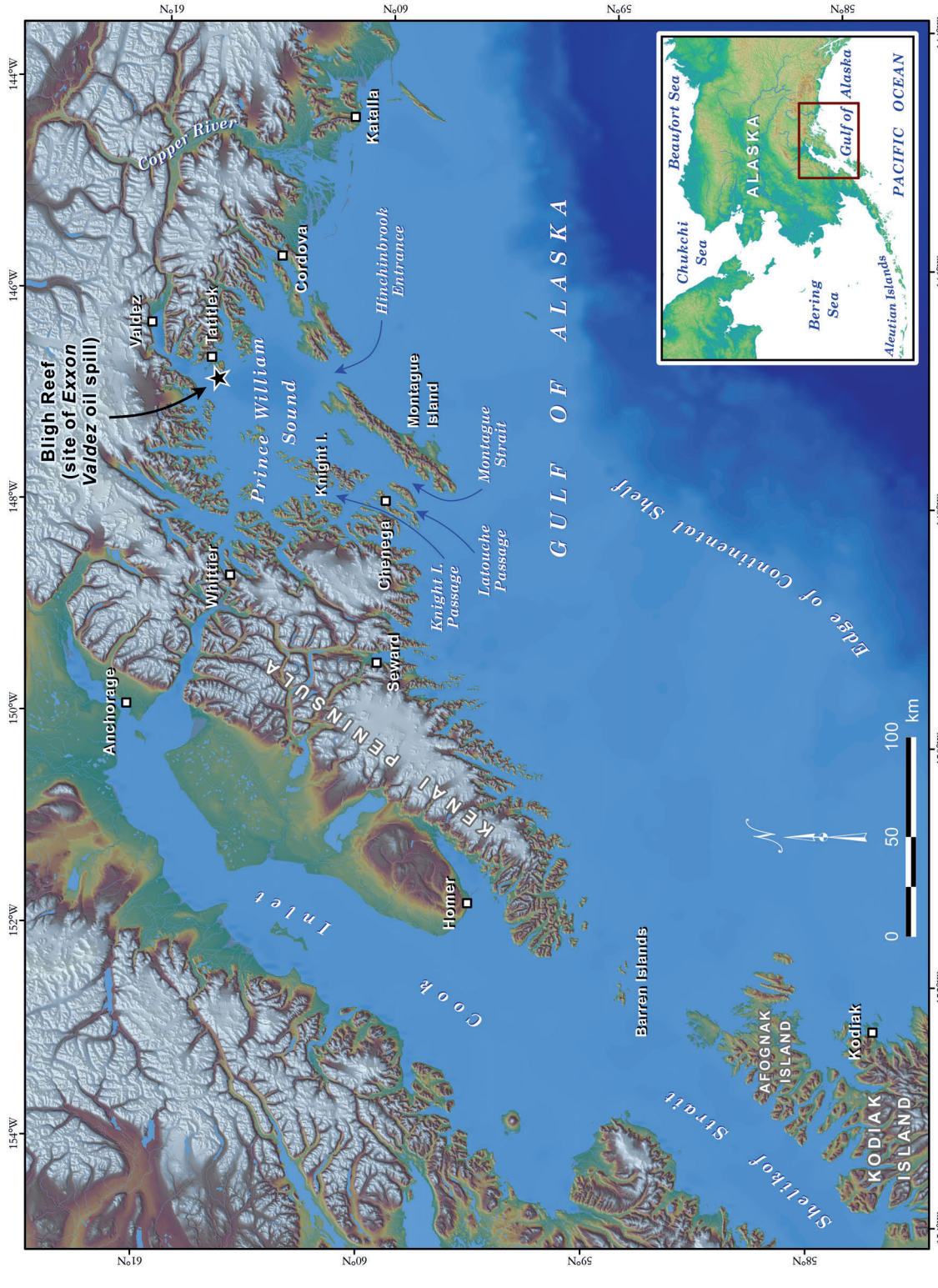


Map 1 The general path of the Alaska coastal current and the approximate progression of the oil spill from its source at Bligh Reef in Prince William Sound on March 23, 1989. (Source: Exxon Corporation).



Map 2 Important features of the northern Gulf of Alaska where the *Exxon Valdez* oil spill occurred.

Map 3 An expanded map of western Prince William Sound, identifying important locations mentioned throughout this book.

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USE OF ACRONYMS

Acronyms are often mystical and cryptic, known only to those who work in a discipline. They interrupt the flow of a text, leading the reader to lurch from phrase to phrase. An acronym in a sentence is like a speed bump in a road. At the same time, some acronyms are widely understood and, once grasped, allow one to read a passage without getting bogged down in cumbersome terminology or labels. Here we list the acronyms that will appear frequently throughout this book; all will also be defined on their first mention in a chapter.

ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CYP1A	Cytochrome P450 1A
EPA	United States Environmental Protection Agency
ERA	Ecological risk assessment
EROD	7-ethoxyresorufin-o-deethylase
GC-FID	Gas chromatography–flame ionization detection
GC-MS	Gas chromatography–mass spectrometry
GIS	Geographic Information System(s)
GOA	Gulf of Alaska
FAC	Fluorescent aromatic compounds
MDL	Method detection limit
MAYSAP	May 1991shoreline assessment program
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
OPA 90	Oil Pollution Act of 1990
PAH	Polycyclic aromatic hydrocarbon (singular or plural)
ppb	Part per billion; $ng \cdot g^{-1}$ or $\mu g \cdot L^{-1}$
ppm	Part per million; $\mu g \cdot g^{-1}$ or $mg \cdot L^{-1}$
PWS	Prince William Sound
SCAT	Shoreline Cleanup Assessment Technique
SEP	Shoreline ecology program
SOR	Surface oil residues
SSOR	Subsurface oil residues
TEH	Total extractable hydrocarbons
TPAH	Total PAH
TPH	Total petroleum hydrocarbons
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service

ACKNOWLEDGMENTS

During the more than 20 years since the *Exxon Valdez* oil spill, hundreds of people have contributed in one way or another to the scientific studies that are the foundation of this book. Field teams surveyed oil on shorelines, collected water and hydrocarbon samples, inventoried cultural sites, and conducted counts and surveys of shoreline biota, fish, birds, and sea otters, all the time with extraordinary attention to proper quality control and data management. Ocean Explorer and its captains and crews (especially some awesome cooks!) of many vessels provided the logistical support that made the studies possible. They took the scientists and field crews to all sorts of places, in all kinds of weather, with a deep commitment to safety. Several laboratories, especially Battelle in Duxbury, Massachusetts, conducted sophisticated analyses of environmental and tissue samples for hydrocarbons, again with careful attention to precision, accuracy, and quality control. Statisticians, particularly John Skalski (University of Washington) and Jim Harner (West Virginia University), helped design ways of analyzing complex and uneven data sets and enhanced the statistical reliability of the results.

Placing the science and the data in context requires a wide variety of background information. The staff of the Alaska Resources Library and Information Services in Anchorage, especially Carrie Holba, have been unfailingly helpful. Valuable assistance was provided by personnel with The *Exxon Valdez* Oil Spill Trustee Council; Anchorage's Z. J. Loussac Public Library and its Alaska Collection; and the information and library staff of agencies involved with the *Exxon Valdez* spill, especially Nancy Tileston. Susan S. Howison (Exxon Mobil Corporation) provided all manner of support. For over 23 years, Laura Rustin (L. R. Rustin Research Consulting) has provided unexcelled library and information support, answering reference questions from the simple to the bizarre (often before they were asked), obtaining the most obscure documents, indexing, abstracting, building databases, and much more.

Bringing all the science together into a book rests on the contributions and support of many individuals and organizations other than those whose names appear on the chapter headings. The many Trustee scientists who also conducted studies – and those who supported them – have made important contributions to our knowledge of Prince William Sound, the *Exxon Valdez* oil spill, and its effects. Many of the authors of chapters in this book contributed to its development well beyond the domains of their individual chapters by sharing their findings and perspectives and participating in wide-ranging discussions. Many authors were supported by their home institutions or organizations during the development of their chapters. Steve Moffitt and Sherri Dressel of the Alaska Department of Fish and Game provided the data and models used to update herring recruitment figures in Chapter 13. Carla Christofferson, Dawn Sestito, and Reuben Wilson (O'Melveny & Myers, LLP) and Barat LaPorte (Patton Boggs, LLP) provided critical input on legal issues and their background.

Finally, several individuals deserve special mention, for without their efforts this book would not exist. Dominic Lewis (Cambridge University Press) helped guide us through the publication process. Mike Smith has been a steadfast supporter of science within Exxon Mobil Corporation and helped spearhead this project. David K. Johnson (Exxon Mobil Corporation) provided invaluable help to the editor and authors during the development of the book. Allison Zusi-Cobb (ABR, Inc.) and Betty Dowd (Exponent,

Inc.) applied their drafting and artistic talents to produce the maps and figures, respectively. Kyra Wiens brought a keen sense of style to bear on the prose through her detailed and sensitive editing, and she and Laura Rustin worked assiduously to create uniformity in referencing and ensure the accuracy of literature citations.

All of us who have contributed to this book, and have worked to learn the lessons of the *Exxon Valdez* oil spill, thank all of these individuals, teams, and organizations, and the many others too numerous to mention. This book is theirs as much as ours.

Financial support to conduct these studies, analyze and interpret the results, and publish and communicate the findings over the years has been provided by Exxon Mobil Corporation and the *Exxon Valdez* Oil Spill Trustee Council. The contents of this book, however, do not necessarily reflect the views of the funding sources.

A BIBLIOGRAPHIC NOTE

David K. Johnson and Laura R. Rustin

Over the last 23 years, we have obtained over 20 000 documents requested by the hundreds of Exxon-associated scientists, engineers, and others working on the *Exxon Valdez* oil spill. If nothing else, we have come to deeply appreciate accurate – and *useful* – literature citations that actually help you lay hands on a document. Consequently, we have paid particular attention to the references cited in this volume and have done our best to verify authors, titles, volumes, issues, years, journal names, publishers, agencies, page ranges, etc. We have tested all the URLs included in text and citations.[1]

The body of *Exxon Valdez* literature is large, and it continues to grow. In mid-March 2012, a very broad online literature search for *Exxon Valdez* oil spill citations carried out in 20 scientific and technical databases on the Chemical Abstract Service's STN® bibliographic database service retrieved roughly 2000 citations to scientific papers (after removing duplicates using STN®'s algorithm).[2] We estimate that 800–900 may be unique citations directly relevant to the *Exxon Valdez* oil spill. We say "may be" because "*Exxon Valdez*" has, among other things, become a metaphor and simile; a point in time ("not since the"); a byword for magnitude ("larger/smaller than the"); and a term of comparison ("like/unlike the"). Thus, one has to actually look at retrieved citations to determine their relevance. In addition to these papers, there are conference presentations, books, technical reports, dissertations, and theses.

A comprehensive bibliography of the *Exxon Valdez* literature, too large for inclusion in this printed volume, is available online at www.cambridge.org/9781107027176.

There are three important works that summarize *Exxon Valdez* scientific studies:

- **Wells *et al***. (1995): papers from a symposium of the American Society for Testing and Materials reviewing the work of Exxon scientists.
- **Rice *et al***. (1996): papers from a symposium of the American Fisheries Society reviewing the work of *Exxon Valdez* Oil Spill Trustees' ("Trustees") scientists.
- **Integral Consulting, Inc**. (2006): a critical review of both Exxon's and Trustees' work relating to the recovery of the spill area. Exxon and Trustee scientists were interviewed, and their relevant published papers were examined.

One of the goals of this book is to complement and update these three works.

Other key resources include:

- ***Exxon Valdez* Oil Spill Trustees' Website** (www.evostc.state.ak.us): includes Trustee annual and final reports, plus a great deal of other information. This is an important source because it includes significant information that does not appear in the peer-reviewed scientific literature. There is an online method for searching for specific Trustee projects by year, researchers, injured resource or service, project numbers, titles, or keywords.

[1] The internet URLs (Uniform Resource Locators) cited in the book were tested in January 2013.
[2] Books, dissertations and theses, patents, technical reports, and other non–journal-paper citations were removed. Also, social science, law, business, and humanities papers were not included in the search as STN® does not cover this literature.

- **The Alaska Resources Library and Information Service** (ARLIS; www.arlis.org): a consortium of Alaskan federal and state libraries in Anchorage, including: the *Exxon Valdez* Oil Spill Trustee Council; National Park Service; US Geological Survey; US Fish and Wildlife Service; US Bureau of Land Management; University of Alaska–Anchorage; Alaska Department of Fish & Game; and the US Bureau of Ocean Energy Management. ARLIS has a large collection of Trustee and governmental agency materials. It has a joint, online library catalog with the Anchorage Public Library, the University of Alaska–Anchorage/Alaska Pacific University Consortium Library, and the Anchorage Museum's Bob and Evangeline Atwood Alaska Resource Center. The staff are extremely knowledgeable and helpful.
- **The University of Alaska–Fairbank's Elmer E. Rasmuson Library's Alaska and Polar Regions Collection**: a repository of archaeological artifacts found during the spill cleanup and records from Exxon's *Exxon Valdez* Cultural Resource Program (Chapter 5).
- **Valdez Sciences Website** (www.valdezsciences.com): an Exxon website that has reports and data particularly relevant to this volume, including Prince William Sound polycyclic aromatic hydrocarbons (PAH) in water data (2001–08) (Chapters 3, 12, 13); PAH data particularly related to pink salmon (*Oncorhynchus gorbuscha*) and Pacific herring (*Clupea pallasii*) (Chapters 12, 13); and the results of Exxon's 1991 May Shoreline Assessment Program (MAYSAP), which are important for later studies of the persistence of subsurface oil residues (Chapters 4, 6). The site also includes brochures and reports issued in the early days of the spill that were intended for a more general, less scientific audience.
- **Scientific meetings and conferences**: a considerable body of *Exxon Valdez* work has been reported by all parties at three regular meetings:
  - ➤ *International Oil Spill Conference (IOSC),* organized by the US Coast Guard, the US Environmental Protection Agency, and the American Petroleum Institute (with other occasional sponsoring agencies groups), publishes proceedings with full papers.
  - ➤ *Arctic and Marine Oilspill Program (AMOP) Technical Seminar*, organized by Environment Canada, publishes proceedings with full papers.
  - ➤ *Annual Meeting of the Society for Environmental Toxicology and Chemistry (SETAC)* produces an abstract book but does not publish full papers.

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PROLOGUE

Shortly after midnight on March 24, 1989, the *Tanker/Vessel Exxon Valdez*, fully loaded with its cargo of Alaska North Slope crude oil, grounded on Bligh Reef in Prince William Sound, Alaska. Eight of its 11 cargo tanks ruptured, releasing some 11 million gallons (40 million liters) of oil – about 20% of its cargo – into the icy waters of the Sound. The floating oil rapidly spread, pushed by strong coastal currents. Three days later, a severe winter storm moved in, widening and accelerating the spread of oil and thwarting attempts at containment. As the floating oil reached shorelines, it began coating beaches and intertidal algae and animals with layers of thick, black oil. Over 200 000 seabirds may have died. Commercial fisheries were closed. The spill eventually extended down the Kenai and Alaska peninsulas to beyond Kodiak Island, roughly the distance between Boston and Washington, District of Columbia.

It would be hard to imagine a worse place for an oil spill. Prince William Sound is widely regarded as pristine, and the remoteness and climate of the region present formidable challenges to mobilizing spill responses and cleanup. It supports large populations of charismatic wildlife: sea otters, seabirds, whales, bears, and seals. Tourism, cruises, recreation, and sport fishing are significant activities, and there are economically important commercial fisheries. Alaska Natives also rely heavily on the area for subsistence harvesting.

Because of the spill's magnitude and extent, the natural beauty of coastal Alaska and Prince William Sound, and the involvement of one of the world's largest corporations, the spill commanded intense public and media attention for years. Images of oiled sea otters and seabirds and of shorelines awash with oil were played and replayed. Speculations about long-term devastation of populations were rampant. Even now, more than 20 years later, the *Exxon Valdez* oil spill remains the benchmark against which other oil spills are often measured.

As the oil spread, there were urgent calls for action. Understanding and documenting how the environment and natural resources were affected by the spill demanded the rigor, objectivity, and clarity of science. But the normal scientific process – framing hypotheses, designing experiments, conducting tests, marshaling and managing data, developing models, and the like – takes time. It was not well-suited to responding to a rapidly unfolding environmental disaster in a wild and contentious setting. And communication in 1989 was not what it is now: there were no cell phones, no GPS, no internet access, little capacity for high-speed data processing, and no Facebook or Twitter. Sometimes we didn't know quite where we were – especially when the fog rolled in.

Despite these challenges, science-based studies were quickly implemented, often on the fly. In many cases, the studies involved using emerging technology that had never been applied to such problems or developing new study designs or techniques to disentangle the effects of the oil spill from everything else going on in a harsh and variable environment. The *Exxon Valdez* spill became the most intensively studied oil spill in history. Multiple scientific studies were conducted by multiple parties, at a cost of multiple millions of dollars, producing multiple (and sometimes contradictory)

Figure 1 The *Exxon* Valdez aground on Bligh Reef, Prince William Sound, Alaska, on March 26, 1989. This view, two days after the spill, is toward the northeast. Reef Island is in the immediate background, with Bligh Island behind that and Ellamar Mountain in the background. (Photo: Erich R. Gundlach).

conclusions. Most of this work focused on injuries to wildlife and the environment and their subsequent recovery from the spill. Although there were substantial initial effects of the spill, most vanished within a few years. Now, more than two decades later, oil from the *Exxon Valdez* has disappeared from all but a tiny portion of the shoreline. Debates continue, however, about whether animals are still exposed to oil residues and, if so, whether there are any harmful effects.

This book is about how scientists unraveled the consequences of a huge environmental disruption – the *Exxon Valdez* oil spill. How were studies designed and conducted? What are the limitations of science? What lessons were learned? The insights and lessons we share in this book are intended to provide guidance to those challenged with responding to other oil spills. But they can also apply to other large environmental disturbances, both natural and human-caused.

Our emphasis throughout this book is on how the tools and approaches of the physical and biological sciences have been applied to understand the dynamics of oil in the environment, oil's effects on the biota, and ecological recovery. With the exception of spill effects on archaeological and related historical/cultural sites, we do not consider studies in the domains of the economic, social, and legal sciences, nor do we include food safety or human health and safety. These aspects are covered extensively elsewhere (for example, Smith, 1992; Hausman, 1993; Jones *et al.*, 1994; Owen *et al.*, 1995; Picou *et al.*, 1997; Field *et al.*, 1999; Sunstein *et al.*, 2002; Carson *et al.*, 2003) and are included in the comprehensive bibliography of *Exxon Valdez* studies that is available for downloading from the publisher's website.[1]

The chapters in this book have been written by scientists from multiple disciplines, most of whom initiated studies shortly after the *Exxon Valdez* spill and who have been involved in assessing its effects ever since. As the studies developed, we shared findings, insights, and impressions with one another, expanding the scope of individual studies well beyond the boundaries of traditional disciplines. We also shared ship time, the beauty (and the weather!) of Prince William Sound, and, yes, fish stories. We developed the collegial, collaborative relationships that are as much a part of good science as statistics or study design.

Our investigations were funded by Exxon Corporation (and, since November 30, 1999, by Exxon Mobil Corporation).[2] From the outset, Exxon insisted on the highest standards of scientific integrity. The approach was to enlist respected, independent-minded scientists to design and implement research to determine the spill's effects and then document the extent of recovery with as much certainty as possible, separating fact from fiction and science from speculation. The association with Exxon, however, raised concerns by some of the public (and some scientists) that the work of "Exxon scientists" was biased or intended solely to cast doubt on the findings of other scientists. The position of Exxon as a defendant in civil litigation with nongovernmental plaintiffs further enhanced the image of

[1] At www.cambridge.org/9781107027176.

[2] So too, albeit indirectly, were the studies carried out by scientists engaged by the *Exxon Valdez* Oil Spill Trustee Council, whose work is funded by the $686.9 million paid by Exxon in its civil settlement with the federal and Alaska governments for environmental damages (http://www.evostc.state.ak.us/facts/settlement.cfm).

scientists funded by Exxon pitted against those working for government agencies or testifying for the plaintiffs. We address this issue in the concluding chapter of the book.

Doubt, disagreement, and criticism are essential parts of the scientific process, of course – this is why it is so important that the findings of investigations be subjected to peer review. Over 800 peer-reviewed scientific papers have been published about the spill, and the work continues. In addition, there are at least a dozen books, hundreds of presentations at scientific meetings, hundreds of technical reports, and over 70 theses and dissertations that deal with the spill.[3] Integral Consulting, Inc. (2006) also produced a comprehensive and independent review, sponsored by the *Exxon Valdez* Oil Spill Trustee Council ("Trustees"), which was based on interviews with governmental and Exxon-supported scientists and an evaluation of the findings in published literature and reports authored by all parties. As a result of all these efforts, we have a much better understanding of the dynamics of oil in marine environments and of how to design and conduct investigations. These studies provide a wealth of knowledge on which responses to future oil spills will depend.

In some respects, this book provides an update of the work presented in the proceedings of two symposia that covered the studies of Trustee scientists (Rice *et al.*, 1996) and Exxon-supported scientists (Wells *et al.*, 1995). Unlike other books about the *Exxon Valdez* oil spill, however, a major goal of this book has been to consider the published work of all investigators – regardless of their funding sources, affiliations, employment, or other considerations. The chapter authors, each an expert in his or her own area of study, have aimed to examine the full breadth of scientific work related to their area and provide interpretations that rest on the firmest foundations of the science. The studies covered in the following chapters evolved over time, often responding to or building on previous studies. The differences in approaches, assumptions, and results provide exceptional insights – not just into what happened, but also into how studies of such large environmental disruptions can and should be conducted.

Much was learned in the process of investigating the many facets of the *Exxon Valdez* oil spill, not only about the dynamics of oil in the environment and the ways in which the spill affected (or did not affect) natural resources, but also about the value and limitations of science in assessing the consequences of environmental disruptions on such a scale. These lessons, which are the capstone elements of this book, are perhaps the most enduring legacy of the *Exxon Valdez* oil spill.

[3] In addition to the scientific literature (including the social science literature), there are also *Exxon Valdez* oil spill related poetry, fiction, children's books, essays, photography, oral history, class projects, and memoirs (for example, Frost, 1990; Spencer, 1990; Chandrasekhar, 1991; Markle, 1999; University of Nebraska, 2001; Larson, 2002; Holleman, 2004; Payerhin, 2004; Bushell and Jones, 2009; Garshelis, 2009), and at least one made-for-TV movie (*Dead Ahead: The* Exxon Valdez *Disaster*, http://www.imdb.com/title/tt0104060/), one composition for soprano and chamber orchestra (Schultz, 1992), one cookbook (Anonymous, 1990), one melodrama (Reichman, 1992), one mystery (Robinson, 1995), one Harlequin romance (Erickson, 1991), and one board game (Lynn, 1989).

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