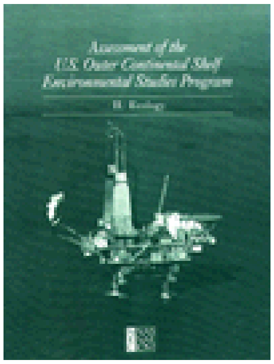
http://www.nap.edu/catalog/1963.html

We ship printed books within 1 business day; personal PDFs are available immediately.



Assessment of the U.S. Outer Continental Shelf Environmental Studies Program: II. Ecology

Ecology Panel, Committee to Review the Outer Continental Shelf Environmental Studies Program, Board on Environmental Studies and Toxicology, National Research Council

ISBN: 0-309-53776-2, 162 pages, 8.5 x 11, (1992)

This PDF is available from the National Academies Press at: http://www.nap.edu/catalog/1963.html

Visit the National Academies Press online, the authoritative source for all books from the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council:

- Download hundreds of free books in PDF
- Read thousands of books online for free
- Explore our innovative research tools – try the “Research Dashboard” now!
- Sign up to be notified when new books are published
- Purchase printed books and selected PDF files

Thank you for downloading this PDF. If you have comments, questions or just want more information about the books published by the National Academies Press, you may contact our customer service department toll-free at 888-624-8373, visit us online, or send an email to feedback@nap.edu.

This book plus thousands more are available at http://www.nap.edu.

Copyright © National Academy of Sciences. All rights reserved.
Unless otherwise indicated, all materials in this PDF File are copyrighted by the National Academy of Sciences. Distribution, posting, or copying is strictly prohibited without written permission of the National Academies Press. Request reprint permission for this book.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Assessment of the U.S. Outer Continental Shelf Environmental Studies Program

II. Ecology

Ecology Panel
Committee to Review the Outer Continental Shelf Environmental Studies Program
Board on Environmental Studies and Toxicology
Commission on Geosciences, Environment, and Resources

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1992

NATIONAL ACADEMY PRESS 2101 Constitution Avenue, N.W. Washington, D.C. 20418

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Support for this project was provided by the U.S. Department of the Interior, Contract No. 14-12-001-30342.

Library of Congress Catalog Card No. 89-63847
International Standard Book Number 0-309-04598-3

A limited number of copies of this report are available from the Board on Environmental Studies and Toxicology, 2101 Constitution Avenue, N.W., Washington, D.C. 20418
S466
Cover photo: Grant Heilman/Grant Heilman Photography
Printed in the United States of America

Ecology Panel

Judith McDowell Capuzzo (*Chair*), Woods Hole Oceanographic Institution, Woods Hole
Edward J. Brown, University of Alaska, Fairbanks
Donald G. Crosby, University of California, Davis
Paul K. Dayton, Scripps Institution of Oceanography, La Jolla
Mark Fraker, BP Exploration, Anchorage[*]
Eileen Hofmann, Old Dominion University, Norfolk
George L. Hunt, Jr, University of California, Irvine
June Lindstedt-Siva, Atlantic Richfield Company, Los Angeles
Ian Nisbet, I.C.T. Nisbet & Co., Lincoln, MA
Robert T. Paine, University of Washington, Seattle
Donald B. Siniff, University of Minnesota, Minneapolis
Michael P. Sissenwine, National Marine Fisheries Service, Silver Spring, MD

Parent Committee Liaison Members

Vera Alexander, University of Alaska, Fairbanks
Edward D. Goldberg, Scripps Institution of Oceanography, La Jolla
Charles Bruce Koons, Exxon Production Research Company (retired), Houston
John J. Walsh, University of South Florida, St. Petersburg

Project Director

David J. Policanksy

---

[*] With Alaska Department of Fish and Game, Anchorage, since Summer 1991

Committee to Review the Outer Continental Shelf Environmental Studies Program

John W. Farrington (*Chairman*), Woods Hole Oceanographic Institution, Woods Hole
Vera Alexander, University of Alaska, Fairbanks
Garry D. Brewer, University of Michigan, Ann Arbor
Judith McDowell Capuzzo, Woods Hole Oceanographic Institution, Woods Hole
Charles Eddy, Los Angeles
Edward D. Goldberg, Scripps Institution of Oceanography, La Jolla
Charles Bruce Koons, Exxon Production Research Company (retired), Houston
Guy Martin, Perkins Coie, Washington, DC
Arthur Maxwell, University of Texas, Austin
James J. O'Brien, Florida State University, Tallahassee
Maurice Rattray, Jr, University of Washington, Seattle
Howard A. Slack, Port Ludlow, WA
John J. Walsh, University of South Florida, St. Petersburg

Project Staff

David Policansky, Project Director
Norman Grossblatt, Editor
Sylvia Tognetti, Research Associate
Bernidean Williams, Information Specialist
Holly Wells, Senior Project Assistant

Sponsor

U.S. Department of the Interior, Minerals Management Service

Board on Environmental Studies and Toxicology

Paul J. Risser (*Chairman*), University of New Mexico, Albuquerque
Frederick R. Anderson, Cadwalader, Wickersham & Taft, Washington, DC
John C. Bailar, III, McGill University School of Medicine, Montreal
Lawrence W. Barnthouse, Oak Ridge National Laboratory, Oak Ridge, TN
Garry D. Brewer, University of Michigan, Ann Arbor
Edwin H. Clark, II, State of Delaware Department of Natural Resources and Environmental Control, Dover
Yoram Cohen, University of California, Los Angeles
John L. Emmerson, Lilly Research Laboratories, Greenfield, IN
Robert L. Harness, Monsanto Agricultural Company, St. Louis
Alfred G. Knudson, Fox Chase Cancer Center, Philadelphia
Gene E. Likens, The New York Botanical Garden, Millbrook
Paul J. Lioy, UMDNJ-Robert Wood Johnson Medical School, Piscataway, NJ
Jane Lubchenco, Oregon State University, Corvallis
Donald R. Mattison, University of Pittsburgh, Pittsburgh
Gordon Orians, University of Washington, Seattle
Nathaniel Reed, Hobe Sound, FL
Margaret M. Seminario, AFL/CIO, Washington, DC
I. Glenn Sipes, University of Arizona, Tucson
Walter J. Weber, Jr., University of Michigan, Ann Arbor

BEST Staff

James J. Reisa, Director
David J. Policansky, Associate Director and Program Director for Applied Ecology and Natural Resources
Richard D. Thomas, Associate Director and Program Director for Human Toxicology and Risk Assessment
Lee R. Paulson, Program Director for Information Systems and Statistics
Raymond A. Wassel, Program Director for Environmental Sciences and Engineering

Commission on Geosciences, Environment, and Resources[1]

M. Gordon Wolman (*Chairman*), The Johns Hopkins University, Baltimore
Robert C. Beardsley, Woods Hole Oceanographic Institution, Woods Hole
B. Clark Burchfiel, Massachusetts Institute of Technology, Cambridge
Peter S. Eagleson, Massachusetts Institute of Technology, Cambridge
Helen M. Ingram, Udall Center for Studies in Public Policy, Tucson
Gene E. Likens, The New York Botanical Garden, Millbrook
Syukuro Manabe, Geophysics Fluid Dynamics Lab, NOAA, Princeton
Jack E. Oliver, Cornell University, Ithaca
Philip A. Palmer, E.I. du Pont de Nemours & Co., Newark, DE
Frank L Parker, Clemson University, Anderson, SC
Duncan T. Patten, Arizona State University, Tempe
Maxine L Savitz, Allied Signal Aerospace, Torrance, CA
Larry L Smarr, University of Illinois at Urbana-Champaign, Champaign
Steven M. Stanley, The Johns Hopkins University, Baltimore
Sir Crispin Tickell, Green College at the Radcliffe Observatory, Oxford, United Kingdom
Karl K Turekian, Yale University, New Haven
Irvin L. White, New York State Energy Research and Development Authority, Albany

Staff

Stephen Rattien, Executive Director
Stephen D. Parker, Associate Executive Director
Janice E. Mehler, Assistant Executive Director
Jeanette A. Spoon, Financial Officer
Carlita Perry, Administrative Assistant
Robin Lewis, Senior Project Assistant

---

[1] This study originally was undertaken under the auspices of the Commission on Physical Sciences, Mathematics, and Resources (see Appendix A).

Preface

The review leading to this report was initiated in May 1986 by the National Research Council (NRC) at the request of the Minerals Management Service (MMS) of the U.S. Department of Interior. Under the auspices of the NRC Board on Environmental Studies and Toxicology, the Committee to Review the Outer Continental Shelf Environmental Studies Program was formed to carry out the overall assignment. Three panels were established, one of which, the Ecology Panel, investigated the ecological aspects of the Environmental Studies Program (ESP). The ecology report is the second in the series of three reports.

It has been 13 years since a previous NRC review (*OCS Oil and Gas: An Assessment of the Department of Interior Environmental Studies Program*) recommended a change from the previous program of supporting descriptive baseline studies to one of carrying out studies that focus on the prediction of impacts from OCS operations and provide information more directly applicable to leasing and management decisions. To date, the ESP has expended approximately $500 million over its 18 year history for environmental studies applicable to lease sales covering most of the U.S. outer continental shelf. This NRC review has addressed the general state of knowledge of specific disciplines (ecology, physical oceanography, and socioeconomics), the adequacy and applicability of ESP studies in meeting program goals, and recommendations for future studies.

The Ecology Panel based its review on several sources, including presentations from ESP staff; briefings by other, independent scientists familiar with the work supported by the ESP; results of workshops on ecological studies held by the panel; and a review of relevant scientific literature and documentation of MMS's planning and implementation process leading to various lease sales. While this report was being prepared, the OCS committee and its panels prepared two reports on the adequacy of environmental information for OCS decisions in response to government requests. The first, requested by President George Bush, dealt with a lease sale off the coast of Florida and two off the coast of California and was published in 1989. The second, requested by MMS, focused on a north Atlantic sale and was published in 1991.

The Ecology Panel acknowledges the assistance and cooperation of the MMS staff, especially D. Aurand, C. Benner, R. Cohen, and W. Lang; the guidance and support of NRC staff, especially D. Policansky, S. Tognetti E. Hobbie, and H. Wells; and the helpful comments provided by reviewers. We also thank D. Davis, who was director of the Board on Environmental Studies when this project first was undertaken, and J. Reisa, the current director. To all, we express our sincere appreciation.

JUDITH MCDOWELL CAPUZZO
CHAIRMAN, ECOLOGY PANEL

Contents

Executive Summary

The Minerals Management Service (MMS) of the U.S. Department of the Interior (DOI) has federal responsibility for oil and gas development on the U.S. outer continental shelf (OCS). From 1954 through 1989, the last year for which statistics have been published, OCS oil and gas development provided almost 8% of total domestic oil production, about 14% of domestic natural gas (with higher percentages in recent years), and more than $93 billion in revenue from cash bonuses, lease rental payments, and royalties on produced oil and gas.

MMS's Environmental Studies Program (ESP) is responsible for the conduct of environmental studies on the OCS and for the collection of information to prepare environmental impact statements and to inform federal management decisions. The ESP (which began in 1973 under the Bureau of Land Management) through 1989 had invested more than $478 million in a wide variety of studies. Ecological studies have accounted for approximately 54% of the ESP budget, for a total expenditure through 1989 of over $259 million.

THE PRESENT STUDY

In 1986, MMS requested that the National Research Council (NRC) evaluate the adequacy and applicability of studies conducted in the ESP, review the general state of knowledge in the appropriate disciplines, and recommend future studies. Under the auspices of the NRC Board on Environmental Studies and Toxicology, the Committee to Review the Outer Continental Shelf Environmental Studies Program was formed to conduct the assignment. Three panels—dealing with ecology, physical oceanography, and socioeconomics—were established to review specific aspects of the assessment. The Ecology Panel investigated the main questions of ecological relevance to OCS oil and gas activities and ecological aspects of the ESP. This report, the second in a series, presents the findings and recommendations of the Ecology Panel.

The panel based its report on several sources, including presentations from ESP staff; briefings by other, independent scientists familiar with the work supported by the ESP; results of workshops on ecological studies held by the panel; and a review of relevant scientific literature and documentation of MMS's planning and implementation process leading to various lease sales. While this report was being prepared, the OCS committee and its panels interrupted their work to prepare two reports on the adequacy of environmental information for OCS decisions in response to government requests. The first, requested by President Bush, dealt with a lease sale off Florida and two off California and was published in 1989. The second, requested by MMS, focused on a north Atlantic lease sale and was published in 1991.

For this report, the panel reviewed documents that were available through 1990. MMS has informed the panel that the ESP continues to evolve, and recent MMS requests for proposals confirm that. MMS officials have also indicated that they are taking into account recommendations in the two recent reports mentioned above.

The Ecology Panel was divided into three working groups: on marine birds, mammals, turtles, and endangered species; on benthic processes; and on fisheries and ecosystems. The panel conducted workshops on each of those topics, focused on the progress of the ESP in assessing the environmental impacts of OCS oil and gas activities, evaluated shortcomings of the ESP, and identified future information needs.

The biological characteristics of the components of marine ecosystems dictated the types of information gathered for evaluation by the ESP and therefore the nature of the panel's review. OCS activities can have ecological effects during exploration, development, production, and decommissioning. The potential ecological effects during each phase are distinct and require a different suite of studies for prediction of their extent and duration. The panel identified six objectives of obtaining information for assessing the environmental impacts of OCS oil and gas activities:

- Characterization of major habitat types.
- Identification of representative species (or major species groups) in the area of interest.
- Description of seasonal patterns of distribution and abundance of representative species (e.g., identification of spawning and feeding grounds).
- Acquisition of basic ecological information on key or representative species (e.g., trophic relationships, habitat requirements, and reproduction).
- Determination of basic information on factors that determine the likelihood that various populations and communities would be affected by OCS activities, and the potential for recovery.
- Determination of potential effects of various agents of impact (e.g., spilled oil, operation discharges, noise, and other disturbances).

Information for the first three objectives is needed before leasing; more site-specific information for the second three is needed after leasing (during exploration, development, and production). All six objectives were kept in mind in the review of various components of the ESP and the preparation of recommendations for future studies.

MARINE BIRDS, MAMMALS, AND TURTLES

A major goal of many studies in the ESP has been to provide an inventory of the seasonal distribution and abundance of species in each OCS area. That information is necessary for describing the biological resources present, identifying places and times when populations are especially vulnerable to local impacts. Ideally, such early studies would lead to monitoring of selected sites so that natural rates of change and processes could be identified before oil is produced. In most instances, the panel found that this information provided a valuable assessment of the resources present.

The ESP has provided a major impetus for the study of marine birds and mammals in the coastal waters of the United States. Through those studies, knowledge of the distribution and abundance of breeding North American seabirds, the pelagic biology of seabirds in U.S.

waters, and the distribution and abundance of marine mammals (especially cetaceans) has increased dramatically. The distribution and abundance of sea turtles in OCS areas (especially in the Gulf of Mexico) have received much less attention. There have been relatively few detailed studies of the responses of populations of marine birds and mammals to environmental impacts of different OCS activities (e.g., responses to oil spills and noise impacts on cetaceans) or environmental change. Further investigations are needed to increase understanding of the vulnerability of specific populations to impacts of OCS activities and their ability to recover from them.

BENTHIC PROCESSES

One of the major achievements of the ESP is the characterization of benthic habitats of the U.S. OCS, including analysis of benthic fauna and physical and chemical characteristics. The dominant features and processes of OCS areas are adequately described to support more detailed site-specific studies on processes that govern shelf environments and evaluation of the impacts of environmental perturbations. In most instances, however, understanding of spatial and temporal variability in continental shelf habitats is limited, and there is little understanding of the relative vulnerability of the habitats to environmental impacts of OCS oil and gas activities. Studies have been conducted primarily in frontier areas of the OCS, and there has been little postexploration study of effects. Future research should continue to move toward gaining a better understanding of benthic processes that influence the fate, transport, and effects of OCS operational discharges and understanding of the impacts of other OCS-related disturbances, including those in nearshore and onshore habitats.

FISHERIES AND ECOSYSTEMS

Qualitative assessment of the responses of fishery resources to environmental impacts of OCS activities have received little attention from the ESP except in the Alaska OCS region. Studies have been directed mainly at understanding the response of early life-history stages (i.e., eggs and larvae) to oil spills (through experimental and modeling approaches), sublethal effects of petroleum hydrocarbons on fishery resources, and habitat and distribution. There have been relatively few quantitative assessments of the effects of OCS oil and gas activities on fishery resources.

Mathematical models of fisheries and ecosystems should play an important role in assessing the effects of OCS activity, although they must be used with caution. Models have been developed to assess the acute effects of oil spills on resource species, but many models require better integration with observational data. Models of the fate and effects of chronic discharges require further development.

GENERAL CONCLUSIONS

The Minerals Management Service's mandate to assess potential impacts of OCS activities, as specified in the OCS Lands Act as amended in 1978 and in other authorities, although reasonable from the viewpoint of public policy, required the acquisition of information and the development of predictions that could not be accomplished with the available time, resources, and scientific expertise. Therefore, MMS has allocated its resources to studies that support specific lease sales at the expense of longer-term studies that would have provided a better scientific basis for prediction and assessment of impacts of OCS activities.

In general with a few exceptions, the panel found that the information available on inventories and distribution of marine birds and mammals and the characterization of benthic environments were adequate to define the resources at risk from OCS activities. The principal exception to that finding is the lack of information for OCS areas in the Gulf of Mexico, specifically on the at-sea distribution of birds and mammals, the distribution and abundance of sea turtles, and characterization of benthic communities sufficiently detailed to support leasing decisions. In addition, data on seasonal and yearly variation of many ecological variables of OCS areas are lacking.

There has been a lack of ecological process-oriented programs for many regions of the OCS, studies that would yield information on ecological processes, population dynamics of significant species, and interactions between physical and chemical processes and biological communities. Such information is needed to support assessments of the sensitivity and vulnerability of biological communities to OCS-related activities, and it can also provide a basis for developing strategies for reducing impacts and mitigating them. Studies linking an understanding of physical and chemical processes, of their effects on biological communities, and of the fate and transport of OCS-related discharges are critical during all phases of OCS oil and gas activities. Those studies should assess not only the short-term effects of exploratory drilling on the OCS, but also the long-term effects of chronic discharges during development and production. The latter point was recommended in an earlier review of the OCS oil and gas program.

Within the ESP, there has been a lack of focus on the impacts of OCS activities on nearshore and onshore communities that, although unlikely to be affected during exploration, could be seriously affected when shore-based facilities are constructed or spilled oil moves ashore. Concern for nearshore and onshore communities was highlighted in earlier studies, especially regarding areas where critical habitats of endangered or threatened species could be affected (e.g., the Gulf of Mexico).

MMS's environmental impact analyses to date have emphasized the potential impacts of spilled oil. More attention needs to be given to other potential impacts of OCS development and production, including those associated with the discharge of drilling fluids, produced waters, spill dispersants, and other chronic discharges, in addition to ship and aircraft traffic, onshore development, pipeline construction, removal of facilities and possible cumulative effects of petroleum-related industrialization on organisms and their habitats.

Regional programs within the ESP vary from one region to another in the scientific quality of completed studies, the integration of data from different disciplines, and the acquisition of critical information. The variation was also recognized by the NRC's Physical Oceanography Panel in its review of the ESP. MMS should sharpen its focus on specific scientific hypotheses in developing its strategies for the acquisition of ecological information that can be incorporated into regional study plans. Strengthening the scientific bases of its strategies would result in less-fragmented studies that are better integrated across disciplines and regions and more closely fulfill the mandate for assessing the impacts of OCS oil and gas activities.

Although some extensive data sets have been acquired (especially resource inventories), MMS has not yet established a data management system that will allow it to determine effectively where its effort has been expended or where biological resources are. The panel understands that MMS is again working on the development of a computerized data management system that is intended to permit retrieval of data on study effort, as well as on the distribution and abundance of organisms. While MMS has recently made an effort to have the results of ESP research published in the peer-reviewed literature, many of the earlier studies were not treated in this way.

GENERAL RECOMMENDATIONS

The panel offers six general recommendations for future ESP ecological studies.

- **The ESP should support more ecological process-oriented studies and studies of ecological relationships designed to predict environmental impacts of OCS oil and gas activities.**

A major achievement of the ESP was the characterization of benthic habitats and the distribution of bird and marine mammal populations. Although identification of resources at risk and characterization of habitats will still be required in new frontier areas of the OCS, the need for only broad-scale survey work has passed. Future research should focus on process-oriented programs designed to evaluate mechanisms that control the distribution of populations and communities, such as trophic links between benthic habitats and pelagic communities. The research should focus on the appropriate temporal and spatial scales. For example, the processes by which and the rates at which populations recover from disturbance must be understood in all habitats affected by OCS-related activities. In addition, there is a critical lack of understanding of the proper temporal and spatial scales for evaluating OCS-related impacts, especially on benthic areas. Existing data (data from MMS, data on fisheries, and any other available data) should be analyzed and used to discern proper scales for future research. It is critical to use information gained from studying OCS impacts and attempts to mitigate them in planning future activities. In other words, OCS activities should be treated as scientific experiments whenever possible.

MMS, through the National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program (NOAA/OCSEAP), supported the development of analytical chemical techniques for determining concentrations of hydrocarbons and biochemical techniques for examining sublethal effects of hydrocarbon contaminants, metabolites, and reaction products. Advances in methodology have progressed in the scientific community at large with funding from various sources. These techniques have improved understanding of the fate and effects of hydrocarbon contaminants in the marine environment. MMS should incorporate them into future study plans to improve understanding of the biogeochemistry of hydrocarbons that might affect benthic ecosystems.

The vulnerability of different shelf habitats to discharges from OCS oil and gas activities and the mechanisms that control recovery are not well understood. MMS should continue to direct its efforts toward a greater understanding of the mechanisms involved in habitat restoration and recovery.

For birds, MMS should promote studies of processes responsible for foraging aggregations, both near and away from breeding colonies, and integrate them with work in other specific disciplines (physical and biological oceanography, fisheries, etc.). MMS should cooperate with other organizations to take advantage of and help support current long-term studies of reproductive ecology that are developing data on population and community processes. MMS should conduct additional surveys of migratory routes to identify areas of concentration and their timing. For marine mammals, MMS should ensure that the emphasis of studies on high-profile species is not at the expense of others, less visible, that may be more sensitive or vulnerable.

OCS oil and gas activities constitute only a portion of all human activities in the coastal and continental shelf areas (e.g., commercial fishing, shipping, sewage discharge, etc.) that can have adverse impacts on ecosystems and living resources. Thus, an understanding of the interactions of OCS activities and other disturbances is needed for an assessment of absolute and relative environmental impacts of OCS oil and gas activities.

In addition, OCS oil and gas development could have serious immediate and chronic long-term effects on intertidal and nearshore habitats. Because of their popular appeal and exposure to waterborne oil and debris, the narrow intertidal habitats are among the most valuable, yet vulnerable, marine habitats in the world. Although these fragile habitats and ecosystems are inshore of the legal OCS limits, they are vulnerable to the effects of OCS oil exploration and development and must be better represented in MMS's studies.

- **More emphasis is needed on long-term and postlease studies that are directed toward a better understanding of the environmental impacts of OCS development and production.**

Until recently, ESP studies have focused on preleasing activities, primarily in frontier regions of the OCS, and not on the effects of exploration, development, and production. Almost all the natural patterns represent time scales that must be evaluated in terms of decades, rather than years; and it is absolutely critical that long-term (multiyear) postlease studies be established. Postlease research involving exploration, development, and production must include long-term programs that can discriminate between natural changes and OCS-related changes and can discern interactions of OCS activities with other human activities in specific regions. Longterm studies, including time-series analysis (such as those conducted in the California Cooperative Fisheries Investigation), should define the spatial and temporal extent of the impacts of OCS activities. For birds, MMS should establish a subset of potentially vulnerable colonies and should run a statistically based program to monitor numbers and reproductive biology of selected species during leasing, exploration, and production. Detailed long-term monitoring studies should also be done for selected species of marine mammals. The development of monitoring programs to verify predicted effects can be used to ensure that effects do not reach unacceptable levels. MMS should hold a workshop and collaborate with other agencies (e.g., Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS), state agencies) to identify useful indicator species and to outline the types of long-term monitoring studies that could be done to verify the predicted effects, and detect the possible unforeseen effects of OCS activities in different regions.

One important component of postlease analysis is the understanding of the long-term effects of oil spills on both the OCS and nearshore habitats. Therefore, MMS should take advantage of accidental and experimental oil spills for research, to examine the persistence of hydrocarbons in the marine environment, to identify the processes related to the degradation of hydrocarbons, and to define the mechanisms that control the recovery of specific biological communities as it did recently with the *Nestucca* spill off the Washington coast. It is extremely important that the sites of large oil spills receive periodic restudy. MMS should hold a workshop, together with other agencies, to develop contingency plans for responding scientifically to different kinds of oil spills in different areas and to use them as a means for verifying otherwise unverifiable hypotheses concerning the effects of oil and marine living resources and the ecosystems of which they are a part. The data collected from many studies of the *Exxon Valdez* oil spill were not available for review and incorporation into this report. When most of the data have been made public and peer-reviewed, we are likely to gain valuable insights about the fate and effects of spilled oil in subarctic environments.

• Models are important for understanding ecosystem processes and environmental impacts of OCS activities. However, the development of models requires observational data for verification, and use of models does not replace the need for further work in the assessment of environmental impacts of OCS activities.

Modeling is an important tool that can provide insights into a variety of ecosystem processes and should be used not as a substitute for field programs, but in conjunction with field programs to identify specific information gaps. To improve predictive capability for ecosystem modeling, MMS should:

—Use models to identify critical data gaps and processes that must be understood to predict accurately the possible environmental impacts of OCS activities.
—Provide data on rates and processes for models.
—Take advantage of theory and techniques that are being developed for constructing ecosystem models.
—Take advantage of modeling expertise that exists outside of current MMS contractors.

In all cases, models should be tested against and calibrated with field observations before their outputs are used to assess and manage OCS environmental impact.

• MMS needs a data management system that is accessible in a timely manner and allows the integration of information from different disciplines.

MMS has produced a large quantity of data—some interpreted, some not. Improvement is needed in MMS's data management, including synthesis, storage, and retrieval. MMS should continue to develop integrated data bases on biological resources potentially at risk. The data bases should be reproducible as maps. Formats should permit ready retrieval on a geographic basis. GIS systems could be developed and used to help organize and integrate multidisciplinary geographic data in each OCS region. MMS should continue to develop information exchanges with other agencies. In addition, MMS should continue to encourage the publication of study results in the peer-reviewed scientific literature. Final reports can be difficult to find, and they often are not critically reviewed or integrated for an understanding of broad-scale impacts of OCS-related activities when not published in peer-reviewed scientific literature.

• MMS should sharpen its focus on the specific scientific hypotheses underlying its strategies for the acquisition of information so that the information can be incorporated into regional study plans, and should strive to integrate regional study plans across disciplines and regions.

MMS needs to develop study plans that include more hypothesis-testing and greater recognition of the spatial and temporal scales on which effects of specific OCS activities can occur.

- **MMS should help in the curatorship of the large collections obtained during its studies.**

MMS requires (appropriately) that samples be competently identified and that voucher specimens be maintained. It is critical for determining whether change has occurred that all specimens be available for inspection. Indeed, frozen tissue samples from selected animals also offer extremely important reference information for assessment of future impacts of OCS activities. In order to provide taxonomic continuity for future MMS-supported research, MMS should support the systematists that made the benthic programs possible, and especially should support the extremely important long-term curatorship of archived samples. The marine mammal tissue bank being developed by NMFS (to which MMS contributes) could usefully be expanded to include birds and fish.

1

Introduction

OUTER CONTINENTAL SHELF ACTIVITIES

Magnitude and Management

Leasing of oil and gas resources on the OCS is managed by the Department of the Interior (DOI) Minerals Management Service (MMS). MMS was formed in 1982 as a result of DOI Secretary James Watt's desire to consolidate responsibility for offshore oil and gas development in one agency. MMS includes some functions and personnel previously in the Bureau of Land Management (BLM) and the U.S. Geological Survey (USGS). Federal responsibility for development of mineral resources and conservation of natural resources on the OCS was established by the Outer Continental Shelf Lands Act (OCSLA) (67 State 462) of 1953, the Submerged Lands Act (67 State 29) of 1953, and the OCSLA amendments of 1978.

From 1954, when the oil and gas leasing program began, through 1989, the last year for which statistics have been published, federal offshore oil and gas development has provided almost 8% (8.2 billion bbl) of total domestic oil production, about 14% (83 trillion cubic feet) of domestic natural gas, and over $93 billion in revenue from cash bonuses, lease rental payments, and royalties on produced oil and gas (MMS, 1990a,b). In 1988 alone, the OCS provided approximately 10.8% of the domestic oil produced, 24.6% of domestic natural gas, and over $3 billion in revenue (MMS, 1990b). From 1954 through 1989, there were 102 lease sales; they offered 138,726 tracts that included 756,033,873 acres. Only 11,513 (8.3%) of those tracts, which included 59,316,001 acres (i.e., 7.8% of the acreage offered), were actually leased. Table 1-1 provides a regional breakdown of lease offerings and sales in 1954-1989. Table 1-2 shows, by region, the number of leases active in 1989.

In 1974, as part of a strategy to deal with the nation's energy problems after the Arab oil embargo, President Nixon directed the Secretary of the Interior to increase the amount of acreage leased. Congress was concerned, however, that federal administration of the leasing program and federal regulation of OCS development constituted a closed decision-making process involving the Secretary of the Interior and industry (Congressional and Administrative News of the U.S. Code, 1978). At the time the amendments to the OCSLA were passed, Congress expected that offshore production would provide the largest domestic source of oil and gas into the 1990s (Congressional and Administrative News of the U.S. Code, 1978). One purpose of the amendments was to provide a statutory mechanism for public participation in decision-making to increase public confidence in this government activity (Congressional and Administrative News of the U.S. Code, 1978).

TABLE 1-1 Lease Offerings and Sales, 1954-1989

		Leases Offered		Leases Issued		Leased Percentage	
Region	Number of Sales	Tracts	Acres	Tracts	Acres	Tracts	Acres
Alaska	15	17,766	98,013,764	1,481	8,181,465	83	8.3
Atlantic	8	9,160	51,520,602	410	2,334,205	45	4.5
Gulf of Mexico	68	109,897	596,676,112	9,152	46,260,319	83	7.7
Pacific	11	1,903	9,823,395	470	2,540,012	24.7	25.9
TOTALS	102	138,726	756,033,873	11,513	59,316,001	8.3	7.8

Source: MMS, 1990a.

TABLE 1-2 Active Leases, 1989

Region	Active Leases	Percentage of Active Leases	Acres Leased	Percentage of Acres Leased
Alaska	938	14.7	5,168,479	15.7
Atlantic	71	1.1		404,216
1.2				
Gulf of Mexico	5,228	82.1	26,671,953	81.0
Pacific	130	2.1	671,752	2.1
TOTALS	6,367	100.0	32,916,400	100.0

Source: MMS, 1990b.

The OCS lease-sale schedule is established in accordance with a 5 year plan that sets forth the size, timing, and location of proposed leasing activities. The plan is developed in a 2-year process that includes consultation with coastal states and other federal agencies and an opportunity for public comment. Beginning in 1983, lease sales were offered on an areawide basis, instead of for selected tracts, so the numbers of blocks and leases were increased and more exploratory wells were encouraged in frontier areas (areas with no oil and gas production), such as areas of deep water. The current plan, effective from mid-1987 to mid-1992, calls for one sale every 3 years in each of 21 of the 26 OCS planning areas (see Figs. 1-1 and 1-2), except in the Gulf of Mexico, where sales are annual. Sales in several environmentally sensitive subareas have been deferred indefinitely (MMS, 1987a). Since 1987, additional deferrals, cancellations, and leasing moratoria have occurred.

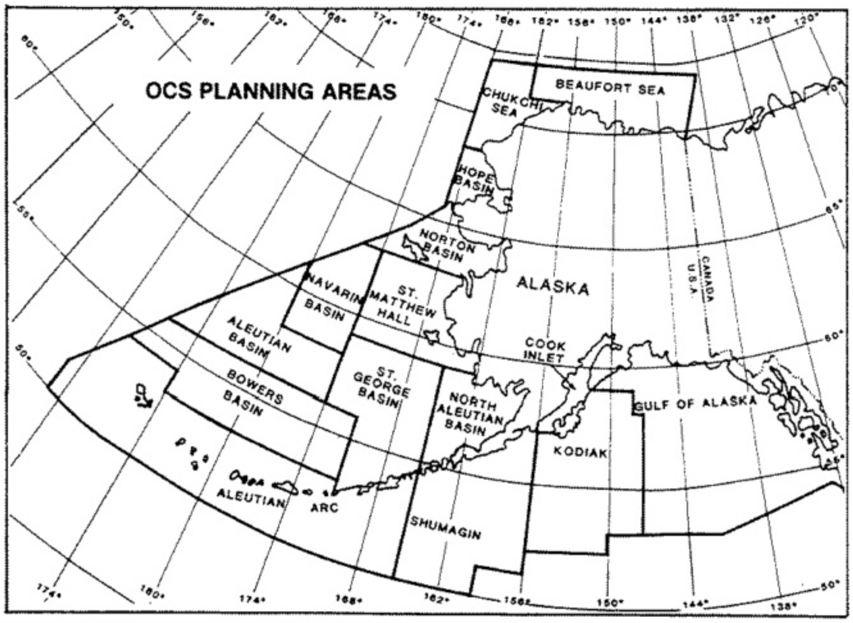


Figure 1-1
Outer Continental Shelf planning areas (Alaska). Source: MMS, 1987a.

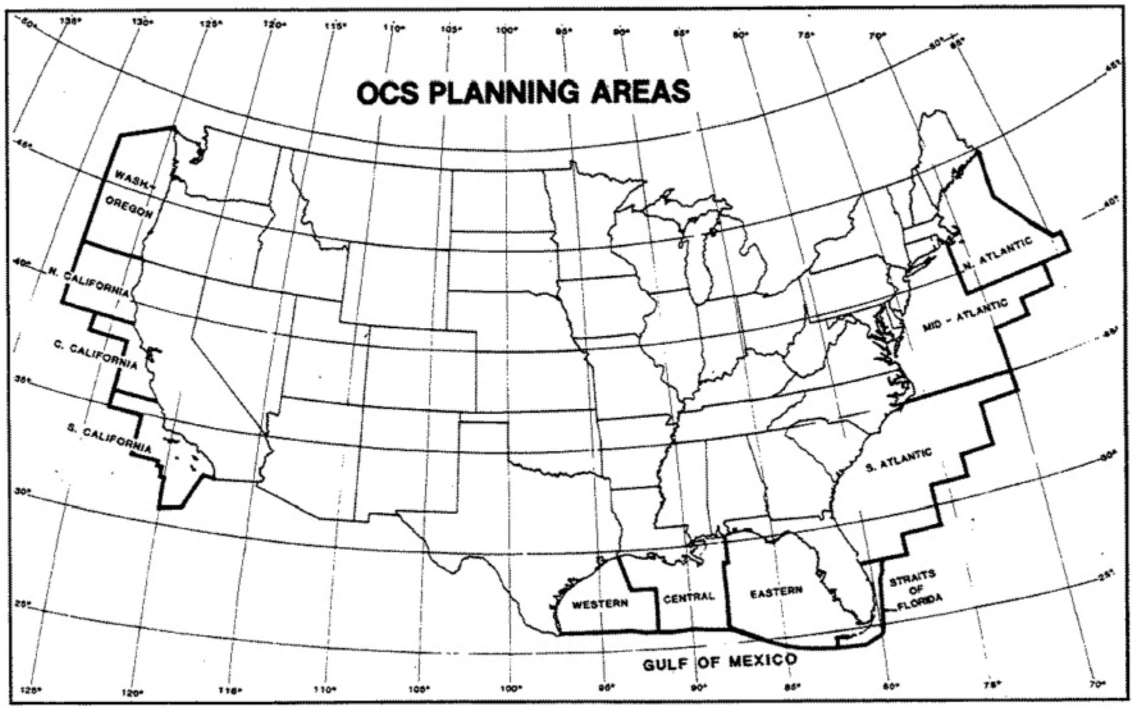


Figure 1-2
Outer Continental Shelf planning areas (contiguous United States). Source: MMS, 1987a.

Environmental Concerns

Offshore drilling has been conducted since the beginning of this century, mostly in shallow state waters. Until 1969, potential environmental damage was primarily a local concern in the affected states. Then, in January 1969, oil-spill damage resulting from a major blowout at a Union Oil platform in the Santa Barbara Channel brought environmental concerns to national attention (Congressional and Administrative News of the U.S. Code, 1978). That oil spill covered 1062 km^2, including 241 km of coastline (Cicin-Sain, 1986).

The potential impacts of oil spills resulting from OCS development and production on resources, such as fisheries, and endangered species have caused environmental concern. Other sources of potential adverse impacts associated with OCS development include the discharge of produced water and drilling muds and the chronic loss of oil at drilling sites. Seismic surveys and the construction and operation of platforms and pipelines can disturb wildlife and interfere with commercial recreational and subsistence fishing activities, and potentially adverse socioeconomic impacts are associated with the construction of onshore support facilities (NRC, 1978; MMS, 1987b). The potential for long-term, chronic environmental effects is also a source of concern (Table 1-3; Boesch and Rabalais, 1987). The effects of oil spills and drilling-mud discharges have been the subject of previous National Research Council (NRC) reviews (NRC, 1975, 1983, 1985). Table 1-3 summarizes some of the major potential effects of OCS exploration and development activities but is not exhaustive. Other potential effects include pressure effects of some types of seismic surveys, disturbance of the seabed as a result of rig emplacement and platform installation, and noise at all postlease phases of OCS activity—oil spills are also possible during the exploration stage and there are potential impacts in post-production activities such as the removal of platforms.

Oil discharged from OCS operations has been estimated to contribute approximately 1% of oil inputs in the world's oceans from all sources (NRC, 1985), but it is a major source of public concern. In 1970-1989, there were 1,784 spills of more than 1 bbl each from OCS leases in the Gulf of Mexico, of which 80 were over 50 bbl, for a total estimated spillage of over 176,000 bbl (Table 1-4). In the Pacific in the same years, there were 28 spills, all of 1-50 bbl each, for a total of 165 bbl. Natural seepage in the Pacific OCS for the period is estimated to have been more than 28,000 bbl. Total spillage and seepage for both regions in 1970-1989 thus was around 205,000 bbl (MMS, 1990a). In 1964-1989, there were 22 oil spills of more than 1,000 bbl each from OCS leases. An estimated total of 447,522 bbl was spilled. Table 1-5 provides the location and type of accident for those spills—all but one of which were in the Gulf of Mexico.

Oil also reaches the marine environment from natural sources (e.g., marine seeps and sediment erosion), transportation (including tanker operations, dry-docking, marine terminals, bilge and fuel oils, and tanker and nontanker accidents), atmospheric deposition, and municipal wastes (refineries, nonrefining industrial wastes, urban runoff, river runoff, and ocean dumping) (NRC, 1985).

Impacts to marine communities can occur during exploration, development, and production (Neff et al., 1987) as well as post-production activities. Potential impacts associated with each stage are distinct and require different suites of studies for prediction of their extent and duration. Exploration and production activities can result in the discharge of several classes of contaminants, including petroleum hydrocarbons (from drilling fluids, produced waters, and spillage) and trace metals (from drilling fluids and produced waters). The relative importance of each contaminant class depends on previous exploration and production activities and on the operational practices in a given area (Boehm, 1987).

During exploration, drilling results in the discharge of sediment, drill cuttings, and drilling fluids to the seafloor (Neff et al., 1987), in addition to the disturbances of the environment caused by the placement of drilling platforms. Drilling fluids are recirculated to cool and lubricate the drill bit and are separated from drill cuttings on the drill rig. Fluids and

TABLE 1-3 Major Activities in the Development of an Offshore Oil and Gas Field and Their Potential Effects

Activities	Potential Effects
EVALUATION	
Seismic surveying	Noise effects on fishes and mammals
EXPLORATION	
Rig fabrication	Dredging and filling of coastal habitats (mostly overseas)
Rig emplacement	Seabed disturbance due to anchoring
Drilling	Discharge of drilling fluids and cuttings; risk of blowouts
Routine rig operations	Deck drainage and sanitary wastes
Rig servicing	Discharges from support vessels and coastal port development
DEVELOPMENT AND PRODUCTION	
Platform fabrication	Land use conflicts and increased channelization in heavily developed areas
Platform installation	Coastal navigation channels; seabed disturbance resulting from placement and subsequent presence of platform
Drilling	Larger and more heavily concentrated discharges of drilling fluids and cuttings; risk of blowouts
Completion	Increased risk of oil spills
Platform servicing	Dredges and coastal port development; discharges from vessels
Separation of oil and gas from water	Chronic discharges of petroleum and other pollutants
Fabrication of storage facilities and pipelines	Coastal use conflicts
Offshore emplacement of storage and pipelines	Seabed disturbances; effects of structures
Transfer to tankers and barges	Increased risk of oil spills; acute and chronic inputs of petroleum
Construction of on-shore facilities for transportation and storage	Coastal use conflicts; alterations of wetlands in pipeline corridors
Pipeline operations	Oil spills; chronic leaks
REFINING	
Construction and expansion	Coastal use conflicts
Operations	Increased pollutant loading; depends on regional demands, imports, etc.

Source: Neff et al., 1987.

cuttings are discharged separately (cuttings continuously and drilling fluids after reuse). Other discharges during exploration include water drainage from the deck of the rig that can contain drilling fluids, oil, and small amounts of industrial chemicals used on the rig; treated wastes; and discharges from support vessels. Exploratory drilling occurs for a relatively short duration and relatively little waste is discharged. If no economically viable resource is detected in a new area,

TABLE 1-4 Crude Oil and Condensate Spills of 1 Bbl or More from Offshore Wells on Federal Leases, 1970-1989

	Gulf of Mexico OCS			Pacific OCS			
	Number of Spills			Number of Spills			
Year	1-50 Bbl	More than 50 Bbl	Total Spillage, Bbl	1-50 Bbl	More than 50 Bbl	Total, Spillage, Bbl	Grand Total, Spillage, Bbl
1970	8	5	83,894	0	0	0	83,894
1971	267	7	2,446	0	0	0	2,446
1972	203	1	997	0	0	0	997
1973	178	5	23,125	0	0	0	23,125
1974	80	7	24,453	0	0	0	24,453
1975	109	2	761	0	0	0	761
1976	66	4	5,103	1	0	2	5,105
1977	71	3	1,087	1	0	4	1,091
1978	79	3	1,528	0	0	0	1,528
1979	114	4	2,700	1	0	2	2,702
1980	50	9	2,922	1	0	5	2,927
1981	65	5	5,793	9	0	73	5,866
1982	70	3	1,155	1	0	3	1,177[a]
1983	91	9	2,528	2	0	4	2,556[b]
1984	59	1	378	3	0	36	416[a]
1985	66	5	1,611	1	0	5	1,618[a]
1986	40	2	356	2	0	11	367
1987	34	1	232	2	0	10	242
1988	29	3	15,280	1	0	2	15,287[a]
1989	25	1	479	3	0	8	487
TOTALS	1,704	80	176,828	28	0	165	177,045

NOTE: These figures do not include natural seepage. Natural seepage in the Santa Barbara Channel is estimated at 40-670 bbl/day (14,600-244,500 bbl/year) from more than 2,000 seeps.

[a] These totals include spills for the Alaska OCS: 1982, one spill, 19 bbl; 1984, one spill 2 bbl; 1985, one spill, 2 bbl; and 1988, one spill, 5 bbl.

[b] This total includes two spills totaling 24 bbl on the Atlantic OCS in 1983.

Source: MMS, 1990a.

activity ceases after the drilling of one or more exploratory wells. If oil or gas reserves are found, the possibility of a "blowout" exists, but preventive measures render it unlikely.

TABLE 1-5 Crude Oil and Condensate Spills of 1,000 Bbl or More from Offshore Wells on Federal Leases, 1964-1989

Year	Location	Type of Accident	Number of Barrels Spilled
1964	Eugene Island	Freighter struck platform	2,559
1964	Eugene Island	Platform in hurricane	5,180
1964	Ship Shoal	Platform in hurricane	5,100
1964	Ship Shoal	Platform in hurricane	1,589
1965	Ship Shoal	Well blowout	1,688
1967	West Delta	Anchor damage to pipeline	160,638
1968	South Timbalier	Anchor damage to pipeline	6,000
1969	Santa Barbara Channel	Well blowout	77,000
1969	Main Pass	Anchor damage to pipeline	30,000
1969	Ship Shoal	Ship struck platform in storm	2,500
1970	Main Pass	Well blowout	30,000
1970	South Timbalier	Well blowout	53,000
1973	West Delta	Structural failure/tank rupture	9,935
1973	South Pelto	Storage barge sank	7,000
1973	West Delta	Pipeline corrosion	5,000
1974	Eugene Island	Anchor damage to pipeline	19,833
1974	Main Pass	Hurricane damage to pipeline	3,500
1976	Eugene Island	Shrimp trawl damage to pipeline	4,000
1979	Main Pass	Vessel collided with semisubmersible	1,500
1980	High Island	Pump failure, tank spill	1,456
1981	South Pass	Anchor damage to pipeline	5,100
1988	Galveston	Anchor damage to pipeline	14,944
TOTAL			447,522

Source: MMS, 1990a.

The characteristics and volume of discharged materials during development and production (Table 1-6) differ from those during exploration, and materials are discharged over a longer period. During development and production there are: (1) greater density of wells, each with its own discharge requirements, (2) discharge of produced water or formation water, which contains lower-molecular-weight compounds—mainly hydrocarbons—and smaller amounts of medium- and higher-molecular-weight compounds, (3) increased risk of blowout, (4) greater risk of oil spills during transfer to tankers and barges or in pipeline operations, (5) chronic leakage of petroleum hydrocarbons from platform operations, and (6) potential for decrease in environmental awareness of operating crew with regard to executing and implementing environmental regulations governing the wide array of discharges. The fate of the discharges in the vicinity of a platform will depend heavily on processes at the site, and potential effects will depend on the characteristics of the biological communities involved.

TABLE 1-6 Major Permitted Discharges and Potential Impact-Causing Agents Associated with Offshore Oil and Gas Exploration and Production

Drill cuttings	1,100 MT/exploration well, less for development well
Drilling fluids	900 MT/exploration well, 25% less for development well
Cooling water, deck drainage, ballast water	May be treated in an oil/water separator
Domestic sewage	Primary activated sludge treatment
Sacrificial anodes, corrosion, antifouling paints	Might release small amounts of several metals (aluminum, copper, mercury, indium, tin, zinc)
Produced water (during production only)	Treated in oil/water separator to reduce total hydrocarbon to mean of 48 ppm, daily maximum of 72 ppm

Source: Neff et al., 1987.

The composition of produced waters varies considerably with the nature of the hydrocarbon reserves and geological formations (Collins, 1975; Jackson et al., 1981; Lysyj, 1982). Produced waters consist primarily of an oily brine brought to the surface with produced hydrocarbons (Boehm, 1987). The oil content is usually reduced by gravity separation before discharge, but various organic and inorganic constituents remain. Among the organic constituents are low-molecular-weight hydrocarbons, such as benzene and toluene (Middleditch, 1981; Sauer, 1981; Neff et al., 1987), that are highly water-soluble and can be accumulated by benthic organisms (Armstrong et al., 1979). Discharge of produced waters is regulated by the Environmental Protection Agency, particularly to restrict the concentration of oil and grease. Treatment of produced waters is designed to remove particulate or dispersed oil, but is ineffective in removing dissolved petroleum hydrocarbons, other organic chemicals, or trace metals (Neff et al., 1987).

Benthic systems can also be disturbed during exploration, development, and production, because of increasing turbidity and changes in grain-size distribution in the vicinity of the platform, anchoring rig, and platform structures; dredging for navigation channels and to provide materials (e.g., for causeways and platforms); and coastal port development. Modes of transportation from offshore platforms depend on the product (oil or gas), the amount of production, the distance to shore, the nature of the environment between the platform and the shore, and the capabilities of onshore facilities (Boesch et al., 1987). Thus, assessing the impacts of oil and gas exploration, development, and production requires a detailed understanding of coastal, continental shelf, and slope processes that govern the transport, fate, and effects of discharges from operational activities.

The major questions that must be addressed in an assessment of the impacts of oil and gas exploration, development, and production are the following:

- What is the fate of discharged materials?

- What is the potential for large-scale changes in benthic, pelagic, and coastal communities as a result of OCS operational activities and what is their ecological significance?
- What resources would be affected and what is the comparative sensitivity of different continental shelf habitats to OCS operational activities?
- How predictable are the impacts of OCS operational activities?
- Can the impacts be measured and their causes identified?

Addressing those questions requires both the characterization of OCS habitats through observational studies and innovative experimentation, to differentiate between natural variability and the effects of OCS operational activities. Processes that affect the fate and transport of trace contaminants are many and complex, because biological, chemical, and physical effects can all contribute to the ultimate distribution of contaminants. Determining the dominant processes requires a coherent, integrated field program that is focused on assessing not only the concentration, but also the rate of transport of a contaminant through an ecosystem. In reality, such a field program is exceedingly expensive and too narrow and brief to characterize contaminant transport and effects, particularly long-term effects, adequately. A suite of observation, experiment, and modeling is often required for timely and cost-effective predictive assessments.

THE ENVIRONMENTAL STUDIES PROGRAM

Mandate

Under the OCSLA as amended in 1978, MMS must manage the OCS oil and gas program with consideration for the economic, social, and environmental values of both renewable and nonrenewable resources; for the marine, coastal, and human environments that could be affected; for the laws, goals, and policies of affected states; and for the equitable sharing of developmental benefits and environmental risks among the various regions. Timing and location of leasing must be selected, to the greatest extent practicable, to balance the potential for environmental damage, the potential for discovery of oil and gas, and the potential for adverse impact on the coastal zone (43 U.S.C. §1344).

To balance the benefits of the leasing program with environmental concerns, MMS must conduct environmental studies. The OCSLA establishes two goals for the MMS Environmental Studies Program (ESP). The first goal is to develop information needed for "the assessment and management of environmental impacts on the human, marine, and coastal environments of the OCS and the coastal areas that may be affected by oil and gas development" in the proposed leasing area (43 U.S.C. §1346 (a)(1)). To the extent practicable, studies must be "designed to predict impacts on the marine biota, which may result from chronic low-level pollution or large spills associated with OCS production, from the introduction of drill cuttings and drilling muds in the area, and from the laying of pipe to serve the offshore production area, and the impacts of development offshore on the affected coastal areas" (43 U.S.C. §1346 (a)(3)).

The second goal is to conduct additional studies subsequent to the leasing and development of an area or region as the secretary deems necessary and to "monitor the human, marine, and coastal environments of such an area or region to provide time-series and datatrend information which can be used for comparison with previously collected data to identify important changes in the quality and productivity of such environments, to establish trends in the areas studied and monitored, and to design experiments to identify the causes of changes" (43 U.S.C. §1346 (b)).

The secretary must also each year "submit to the Congress and make available to the general public an assessment of the cumulative effect of activities conducted under this subchapter on the human, marine, and coastal environments" (43 U.S.C. §1346 (e)). Although the assessment should make use of information generated by the Branch of Environmental Studies (BES), the report is prepared by another branch of MMS. (The first such report, dated 1988, was released in 1990.) Under the same section, the secretary must establish procedures for the conduct of the required studies. The OCSLA (43 U.S.C. §1334 (a)(8)) requires the secretary to regulate OCS activities to ensure that they do not prevent the attainment of National Ambient Air Quality Standards.

The secretary must use information prepared as noted here to support leasing decisions, promulgate regulations, set lease terms, and establish operating procedures (Congressional and Administrative News of the U.S. Code, 1978; 43 U.S.C. §1346 (d)).

Environmental information is used to support permit decisions, in addition to lease-sale decisions. Separate permits are required before geological and geophysical surveys, exploration, development, and production can be conducted. Exploration, development, and production plans must be submitted to MMS with an environmental report and a certificate of consistency with state coastal zone management plans (under the Coastal Zone Management Act (CZMA) 16 U.S.C. §1451-1464) from each coastal state affected.

The environmental information is also used as the basis for ensuring compliance with other applicable environmental laws, such as the National Environmental Policy Act (NEPA) (42 U.S.C. §4321-4347). NEPA requires federal agencies to "utilize a systematic and interdisciplinary approach which will insure the integrated use of natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment" and to prepare environmental impact statements before major federal actions. The Endangered Species Act (ESA) of 1973 (16 U.S.C. §1531-1543) requires MMS to consult with the Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) to ensure that OCS activities do not cause harm to endangered or threatened species or damage or destroy their habitats.

Specifically, Section 7 of the ESA (16 U.S.C. §7) requires all federal agencies, in consultation with the Secretary of the Interior or the Secretary of Commerce and to the extent practicable consistent with their primary mission, to use their authority to carry out programs to conserve endangered and threatened species and to ensure that agency actions are "not likely to jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of habitat of such species which is determined by the Secretary, after consultation with the appropriate affected states, to be critical, unless such agency has been granted an exemption . . . ." The act also requires that agencies use the "best scientific and commercial data available" to fulfill those requirements.

The secretary is required to provide a written opinion, based on consultation, as to whether and how a proposed agency action would be likely to jeopardize any endangered or threatened species, including a summary of the information on which the opinion is based. If the secretary concludes that an action would jeopardize a species in question or adversely modify its habitat, he or she must suggest reasonable and prudent alternatives that would not violate the ESA. Once the consultation process has been initiated, the agency proposing the action is prohibited from making "any irreversible or irretrievable commitment of resources [that] has the effect of foreclosing the formulation or implementation of any reasonable and prudent alternative measures" that would not conflict with endangered species preservation.

The OCSLA requires that OCS activities be carried out in distinct phases—leasing, exploration, and development. The courts have held that, when there is insufficient information to determine whether a total action would be likely to jeopardize an endangered species, the secretary can conclude that intermediate activities (leasing and other pre-exploration activities) would not jeopardize a species. The courts did not consider leasing to be an irreversible or irretrievable commitment of resources, because the secretary has the authority to cancel a lease sale at any stage of the process, if there is evidence of jeopardy to an endangered species (North Slope Borough v. Andrus, 642 F.2d 589 (D.C. Cir. 1980); Conservation Law Foundation *v.* Andrus, 623 F.2d 712 (1st Cir. 1979); California v. Watt, 520 F. Supp. 1359, 1387 (C.D. Cal. 1981); Bean, 1983).

Other environmental laws applicable to OCS activities include the Federal Water Pollution Control Act Amendments of 1972 (33 U.S.C. §1251-1375, P.L. 92-500), the Alaska National Interest Lands Conservation Act (16 U.S.C. §3101-3233, P.L. 96487), the National Historic Preservation Act (16 U.S.C. §470-470 w6, P.L. 89-665), and the Marine Protection, Research and Sanctuaries Act of 1972 (33 U.S.C. §1401-1445, P.L. 92-352).

History of the Environmental Studies Program

DOI established its ESP in 1973, in large part to comply with the requirements of NEPA. From its inception, when it was administered by BLM, through 1989, the ESP invested over $478 million in a wide variety of studies, or approximately 0.5% of the total cumulative federal offshore oil and gas revenue of $90 billion. Funding for the program has averaged $30 million per year, but has recently declined to approximately $20 million per year (MMS, 1987c). Most studies are performed by contractors to DOI (MMS, 1988a). In addition to its headquarters (in Washington, D.C. and Herndon, Va.), MMS has an office for each of four regions: Alaska, Pacific, Gulf of Mexico, and Atlantic. The four regional offices (in Anchorage; Camarillo, Calif.; New Orleans; and Herndon, Va.) are responsible for defining and contracting most of the studies.

From 1974 through 1977, baseline studies were conducted in each OCS region where industry expressed an interest in leasing. According to MMS, those were large-scale, multidisciplinary studies designed to provide decision-makers with statistically valid baselines of the geological, physical, biological, and chemical characteristics of the proposed leasing areas (MMS, 1987c). The baseline studies were intended to be used to evaluate the impact of OCS oil and gas operations. After an NRC review (NRC, 1978), MMS abandoned the baseline concept, because the studies were not providing timely and appropriate information for leasing decisions (MMS, 1987c). According to the NRC report, the baseline studies were not useful for management decisions, because they were descriptive and provided no basis for distinguishing natural variability from changes caused by OCS operations. NRC (1978) recommended that the ESP focus on the prediction of impacts of OCS operations and design specific cause-effect experiments to "establish the vulnerability of key species or communities."

In 1975, the Secretary of the Interior established a national OCS Advisory Board to provide guidance and recommendations on the leasing and development process, to receive comments and recommendations from state officials and other interested parties, and to provide a forum for discussion among the federal agencies involved. The advisory board consists of a policy committee, a scientific committee (SC), and six regional technical working groups (RTWGs)-three for the Atlantic region and one for each of the other regions-to review political, scientific, and technical aspects of OCS development, and to balance federal, state, and local interests and public and private interests. The SC was established specifically to provide guidance for and to review the ESP. The RTWGs provide recommendations on the entire leasing and development process, including the ESP (MMS, 1988b) (see Fig. 1-3).

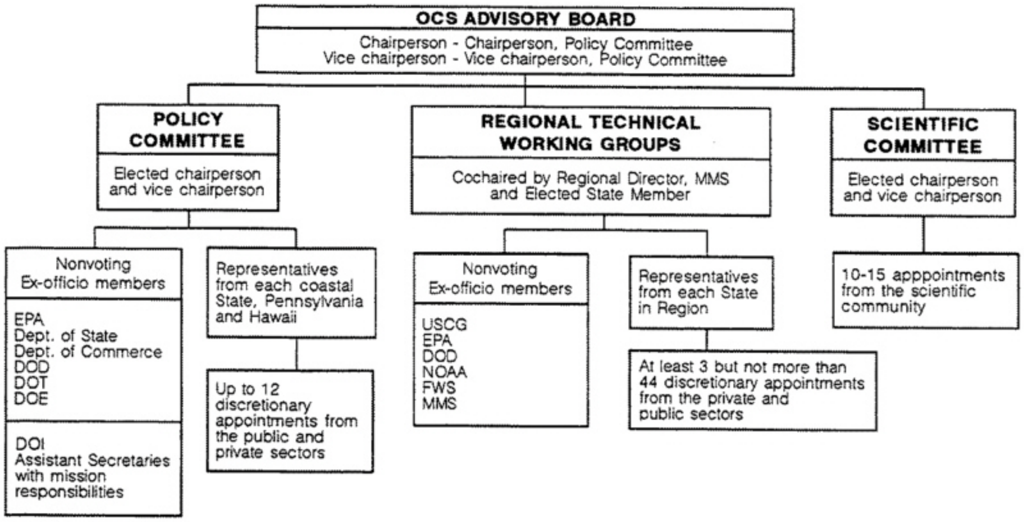


Figure 1-3
Outer Continental Shelf Advisory Board organizational chart. Source: MMS, 1987a.

As a result of the 1978 NRC review, the entire ESP was restructured in late 1978 with the goal of providing more immediately usable results for leasing and management decisions and a framework for establishing study priorities (MMS, 1987c). Under the mandate to establish procedures for environmental studies, guidance in the form of *Study Design for Resource Management Decisions: OCS Oil and Gas Development and the Environment* (BLM, 1978) was prepared by an ad hoc advisory committee; it was adopted by the OCS Advisory Board on April 29, 1978. The guidance document requires identification of management decisions and studies to provide information needed for them (BLM, 1978).

According to Don Aurand (1988), then Chief of the Branch of Environmental Studies, the goals of the ESP are to:

- Provide information on the status of the environment that can be used to predict the impacts of OCS oil and gas development.
- Provide information on how and to what extent OCS development can potentially affect the human, marine, biological, and coastal environments.
- Ensure that information already available or being collected under the program is in a form that can be used in decision-making associated with a specific leasing action or with longer-term OCS minerals management responsibilities.
- Provide a basis for future environmental monitoring of OCS operations, including assessments of short-term and long-term impacts attributable to the OCS oil and gas program.

Planned changes in the program designed to support the current lease schedule include a change of emphasis from prelease general studies to studies of postlease environmental affects, more emphasis on generic studies, and development of a strategy for postlease monitoring (Aurand, 1988; MMS, 1988b).

Development of a Studies Plan

In 1978, a framework was established for setting study priorities on the basis of their importance for decision-making, their timeliness, the generic applicability of their results, the availability of information, and their applicability to issues of regional or ESP concern. To develop a list of study topics, issues are identified by MMS—primarily in the regional offices and by advisory groups and interested parties. The issues are then translated into questions that reflect information needed for decision-making.

The MMS regional offices, with help from the RTWGs and the SC, evaluate the list of study topics for scientific and technical feasibility, information availability, scientific merit, and time required for gathering information. The list is also reviewed by other federal agencies and scientists in the academic community, in state and local governments, and in industry. When the review is finished, each regional office submits a draft of a regional plan for studies to MMS's Branch of Environmental Studies (BES, also referred to as Headquarters) in Herndon, Virginia. Each draft plan includes a statement of regional needs for information, the regional perspective on the priorities of these needs, a list of proposed study topics, and a brief description of the rationale for each proposed study. The BES coordinates the development of a "national studies list" from the proposed study topics and ranks them for funding priority according to a set of criteria. Those criteria, developed jointly by DOI and the Office of Management and Budget (OMB) (GAO, 1988), give priority to studies required to fulfill legislative mandates and other legal requirements and studies that will be completed in time for use in specific leasing decisions. Studies are then funded by MMS from its appropriated budget according to rank, until funds are exhausted. Since 1982, MMS has been providing support for the review, publication, and dissemination of ESP results, including publication in refereed journals (DOI, MMS, pers. commun., 1990).

In Alaska, marine environmental studies have been administered in part by the National Oceanic and Atmospheric Administration (NOAA) as part of the OCS Environmental Assessment Program (OCSEAP), under an interagency agreement with MMS that is renewed every 5 years. When a national studies list is approved, NOAA prepares a technical development plan for studies in the Alaska region (NMFS, 1988a). In FY 1974 through FY 1988, $181.7 million was allocated to OCSEAP for environmental studies, of a total of $228.4 million allocated for the Alaska region ESP (GAO, 1988).

In June 1988, the General Accounting Office (GAO) issued a report that concluded that, because of reductions in funding, the duplication of administrative functions between NOAA and MMS had become less efficient and that consolidation of the programs could save up to $1.3 million a year. GAO recommended that MMS develop alternatives to make its program more efficient and, in the selection of alternatives, consider other issues—such as staffing, public perception of objectivity, and continuity of scientific expertise—in addition to potential dollar savings (GAO, 1988). MMS and NOAA have been working to reduce management duplication by attempting to use NOAA staff for scientific investigation, rather than as technical managers of contracted studies. In practice, it has been difficult to match NOAA/OCSEAP staff skills with MMS needs. However, in response to the GAO recommendation, MMS intends to negotiate an agreement that NOAA will cease to issue contracts by the beginning of the next 5 year agreement in FY 1991 and thereafter propose only inhouse studies. MMS would agree to support the previously agreed-on 5 year work plan (MMS, 1988c). [MMS has informed the panel that in 1991, the agreement ended and MMS has assumed responsibility for former NOAA/OCSEAP activities.]

Implementation of Studies According to Lease-Sale Schedules

The planning process for individual studies has been governed primarily by a lease-sale schedule, which is established in a 5 year planning document. The most recent 5 year program plan is for the period between mid-1987 and mid-December 1992. Most studies must be initiated well in advance of a lease sale or any other decision they are intended to support, if they are to be useful. A prelease 15 month study would normally be included in a regional studies plan approximately 34 months before the beginning of the lease-sale process, which begins with the identification of areas that have hydrocarbon potential. Table 1-7 provides an example of how a prelease study is tied to the planning and implementation steps in the ESP and in the OCS leasing process (MMS, pers. commun., 1988). The actual timing varies with the individual studies and lease sales.

MMS Support of Ecological Studies

From 1973 to 1989, total MMS funding of ecological studies in all regions amounted to $259,658,776. That figure was derived from the MMS environmental studies contracts database by adding the cumulative amounts of funding for studies coded as being related to the topics of biology, endangered species, fates and effects, and baseline studies. A breakdown of the amounts spent on each topic by region is provided in Table 1-8.

THE PRESENT STUDY AND REPORT

In 1986, in response to a request from MMS, the National Research Council's Board on Environmental Studies and Toxicology formed the Committee to Review the Outer Continental Shelf Environmental Studies Program. The committee consists of experts in ecology, energy production, geochemistry, marine geophysics, oil-field technology, geology, law, physical and biological oceanography, policy, and resource management. It is reviewing the adequacy and appropriateness of the studies that are used to support leasing decisions and to predict and manage environmental impacts of OCS activities. The committee's report will include a review of the literature of selected fields and recommendations for directions for the program to follow.

The committee recognized during its deliberations that there are several ways to divide the issues addressed by the ESP and the content of the ESP studies—e.g., into regional, disciplinary (including subdisciplinary), and generic problems. The committee has established three panels to provide reviews of disciplines that make up the ESP. Those panels are focusing on physical oceanography, ecology, and socioeconomics. Between-panel issues and overarching issues for the ESP will be addressed in the report that the committee prepares after it receives and reviews the panel reports. The present report—the second of three panel reports—focuses on ecological aspects of the ESP.

The Ecology Panel recognizes that the ESP is not intended to be a broad, general science program like that of the National Science Foundation. Rather, it is a mission-oriented program, designed to answer questions about the environmental and socioeconomic effects of oil

TABLE 1-7 Planning and Implementation Steps in the OCS Environmental Studies Program and Lease-Sale Process

Month	Step
-34	Draft regional study plan
-30	Final regional study plan
-27	National studies plan
-20	Procurement plan
-17	Draft statement of work
-12	Final statement of work
-7	Request for proposal
-3	Contract
0	Area of hydrocarbon potential identified
1	Call for information: MMS publishes notice of intent to prepare EIS in *Federal Register;* industry invited to indicate interest; interested parties may comment on topics and areas of concern; no decision yet made about proceeding with sale
5-9	Identification of area to be analyzed in EIS, identification of alternatives for EIS, estimation of resources, and preparation of oil spill report for proposed action and for alternatives; draft report of study results due
12	Draft EIS and final report of study results—describes planning area, analyzes potential environmental effects of oil and gas leasing, and discusses mitigating measures proposed to resolve conflicts; followed by public-comment period
13	Public hearing—opportunity for oral comments on draft EIS
14	Close of period for comment on draft EIS
18	Final EIS—assesses comments from state(s) and public; secretarial issue document (SID) prepared that analyzes all issues involved in proposed sale and possible coastal zone consistency conflicts; SID, accompanied by EIS, is sent to assistant secretary for review and decision on whether to issue proposed notice of sale
19	Proposed notice of sale—details terms and conditions of proposed sale, blocks proposed for leasing, stipulations and other mitigating measures to be required, and proposed bidding systems
21	Governor's comments due—used by MMS to develop recommendations to secretary, SID and final EIS sent to secretary; secretary is required to accept recommendations of governor if he or she determines that they provide reasonable balance between national interest and interests of state(s)
22	Final notice of sale—published at least 30 days before sale; specifies date, time, location, blocks to be offered, and terms and conditions of sale
23	Sale—sealed bids opened and read by regional director
24	Bid review—high bids evaluated to ensure receipt of fair-market value; sale results also reviewed by Department of Justice to ensure that awarding leases does not violate antitrust laws
25	Leases issued—bids accepted or rejected within 90 days of receipt; leases issued for accepted bids 1-2 months after sale

NOTES: In this example, 5 years elapse from the completion of a draft regional studies plan to the lease sale. The postlease process includes (1) exploration-plan evaluation and drilling-permit approval, (2) development- and production-plan evaluation and approval (3) pipeline-permit issuance, and (4) lease termination or expiration. Source: MMS, pers. commun., 1988.

and gas exploration and production. Nonetheless, the answers to those questions need to have a basis in sound science.

TABLE 1-8 Expenditures for Ecological Studies by Study Topic and Region, FY 1973-1989

OCS Region	All Ecological Studies	Biology	Endangered Species	Fates and Effects	Baseline
Alaska	115,167,407	63,552,741	27,933,914	21,116,516	2,564,236
Atlantic	40,844,025	13,899,281	7,263,556	5,820,469	13,860,719
Gulf of Mexico	52,896,945	24,633,870	1,909,176	5,211,305	21,142,594
Pacific	44,496,186	22,559,879	4,346,051	4,587,302	13,002,954
Washington	6,254,213	2,514,294	219,747	2,243,579	1,276,593
TOTALS	259,658,776	127,160,065	41,672,444	38,979,171	51,847,096

Source: Compiled by the Ecology Panel from information provided by MMS.

The panel based its report on several sources, including presentations from ESP staff; briefings by other, independent scientists familiar with the work supported by the ESP; results of a workshop on ecological studies held by the panel; and a review of relevant scientific literature and documentation of MMS's planning and implementation process leading to various lease sales. While this report was being prepared, the OCS committee and its panels interrupted their work to prepare two reports on the adequacy of environmental information for OCS decisions in response to government requests. The first, requested by President Bush, dealt with a lease sale off Florida and two off California (NRC, 1989a). The second, requested by MMS, focused on a north Atlantic lease sale (NRC, 1991).

For this report, the panel reviewed documents that were available through 1990. MMS has informed the panel that the ESP continues to evolve, and recent requests for proposals confirm that. MMS officials have also indicated that they are taking into account recommendations in the two recent reports mentioned above.

The Ecology Panel divided into three working groups to address the main issues of ecological concern in OCS development: marine birds, mammals, turtles, and endangered species, benthic processes, and fisheries and ecosystems. Because different ecosystem components require differences in study design, the sections of this report that deal with the different ecosystem components are not exactly parallel in form or equal in length. Studies addressing those issues were identified by keywords in the environmental studies database and by MMS. Table 1-9 provides a breakdown of funding for these types of studies by region (see Appendix B). The biological characteristics of different components of marine ecosystems dictate the type of information gathered for evaluation. Birds are relatively easy to observe, and their identification is straightforward. Few species in the OCS are endangered (some species in nearshore and shoreline habitats are endangered). Many aspects of avian marine ecology are difficult to study experimentally so most studies have been observational. The ESP analyses of birds have focused on the distribution and abundance patterns of species and provide an improved basis for assessment of immediate impact of OCS activities.

Marine mammals (and turtles) are equally identifiable. Many are uncommon or endangered, however, and most are difficult to observe or count. A significant ESP effort has been directed at sea otters and bowhead whales; in some instances, new technologies had to be developed for assessment. Except for studies of sea otters, little information was obtained on the dynamics or ecological (interactive) role of these species in community organization although there is at least one such study in progress.

Many fish species in the OCS are commercially important and are studied and managed by international commissions. Population data on many species have been gathered for decades, but recruitment mechanisms remain poorly understood. Thus, many assessments reflect stock distribution data and not trophic interactions or recruitment dynamics.

Finally, studies of OCS benthic environments are generally based on assemblages of organisms and contain minimal detail on the component species. Many species are undescribed taxonomically, none is on the Endangered Species List, some are economically valuable, and many provide excellent material for experimentation, either in the laboratory or in the field. Thus, assessments of benthic environments tend to describe the distribution and composition of assemblages or, at the other extreme, to identify chronic, sublethal influences on individual species.

The biological characteristics of the components of marine ecosystems dictated the types of information gathered for evaluation by the ESP and therefore the nature of the panel's review. OCS activities can have ecological effects during exploration, development, production, and decommissioning. The potential effects during each phase are distinct and require a different suite of studies for prediction of their extent and duration. The panel identified six objectives that it considers to be important for obtaining information for assessing and monitoring the environmental impacts of OCS oil and gas activities:

TABLE 1-9 Funding Levels for Ecological Studies by Selected Topics and by Region, 1973-1989

OCS Region	Benthic	Fisheries	Birds	Marine Mammals
Alaska	22,840,616	38,399,493	16,009,980	36,312,817
Atlantic	35,765,484	20,033,934	666,004	6,723,340
Gulf of Mexico	43,796,487	12,060,782	1,530,543	1,354,138
Pacific	24,794,427	2,182,739	9,658,635	9,067,222
Washington	1,694,315	567,714	201,824	216,631
TOTALS	128,891,329	73,244,662	28,066,986	53,674,148

NOTE: This table does not include all ecological studies but only topics selected by the panel. Because of this, and because some studies cover several topics, the total amount does not match the total amount in Table 1-8. Source: Compiled by the Ecology Panel from information provided by MMS.

- Characterization of major habitat types.
- Cataloging of representative species (or major species groups) in the area of interest.
- Description of seasonal patterns (including natural variation) of distribution and abundance of representative species (e.g., identification of spawning and feeding grounds).
- Acquisition of basic ecological information on key or representative species (e.g., trophic relationships, habitat requirements, and reproduction).
- Determination of basic information on factors that determine the likelihood that

various populations and communities would be affected by OCS activities, and the potential for recovery.

- ermination of potential effects of various agents of impact (e.g., spilled oil, operation discharges, noise, and other disturbances).

Information for the first three objectives is needed before leasing. More site-specific information is needed after leasing (during exploration, development, and production) so that activities may be stopped or modified before they reach unacceptable levels. All six objectives were kept in mind in the review of various components of the ESP and the preparation of recommendations for future studies.

2

Principles of Assessment

As discussed in Chapter 1, the overall goal of the Environmental Studies Program is to develop information needed to assess and manage environmental impacts associated with oil and gas development on the outer continental shelf and to ensure that the information is available for the decision-making process. The assessment generally consists of three parts: inventory of the resources at risk, estimation of the likelihood of adverse impacts (estimation of risk), and retrospective estimation of damage caused by OCS activities (impact assessment). This report deals with the application of that kind of assessment to marine ecosystems. Marine ecosystems are complex, and many of the interactions within their biotic communities and between biotic communities and the physical environment are poorly understood, so estimation of risk and impact assessment cannot be very precise. Although the ESP is not primarily an ecological research program, many of its projects have provided useful data on the functioning of marine ecosystems, and all its results must be interpreted in an ecosystem context. Evaluation of the success of the ESP in meeting its overall goals requires evaluation of the extent to which it has addressed the specific ecological problems that arise in estimation of risk and impact assessment.

This chapter summarizes the ecological context of the ESP. Specifically, it formulates the principal questions that arise when one assesses impacts of OCS activities on marine ecosystems and the extent to which the questions have to be answered before risks and impacts can be assessed successfully. Chapter 3 summarizes the program itself and evaluates the extent to which it addressed the principal questions.

FOCUS AND GEOGRAPHIC EXTENT OF STUDIES

The mandate of the ESP includes the entire continental shelf of the United States subject to federal leasing—i.e., the area between 3 and 200 miles from the coast—and the adjacent inshore waters and coastal areas. The shelf adjoining the continental United States has been divided into 13 regions (Rabalais and Boesch, 1987). Each region can be divided into domains characterized by oceanographic and biological features, e.g., outer, middle, and inner domains of the Bering Sea shelf, as defined by Iverson et al. (1979) and Coachman (1986) according to hydrographic structure and nutrient flux. Although many species occur in more than one region, generally each region or domain is characterized by a different community of species and often by different relationships among the species and between the species and the food webs on which they depend (e.g., Schneider et al., 1986).

Some knowledge is transferable from one region to another (e.g., effects of oiling on birds does not differ among regions), but the risks posed by OCS activities to different components of marine ecosystems can vary markedly among the regions and domains. Thus, although generic studies can be of great value, data on numbers, population characteristics, ecological relationships, and other factors that affect vulnerability in one region cannot necessarily be applied to another. Similarly, the results of studies conducted elsewhere (e.g., in northern Europe) cannot necessarily be applied to populations in the United States, even in cases where the same species occur in apparently comparable ecological circumstances. Thus, population studies must be conducted in all regions, at least until a basis for extrapolation between regions can be established. It is not necessarily desirable to allocate efforts equally to all regions; allocation of effort should be based on careful evaluation of the data needs in each region.

ENVIRONMENTAL VARIABILITY: DETECTING THE EFFECTS OF OCS ACTIVITIES

Continental shelf habitats of North America contain diverse communities and constitute important economic assets; they are extremely productive and support some of the world's most important commercial harvests of fish and shellfish. Given the proximity of dense population centers in coastal areas, continental shelf habitats are subjected to the impacts of many human activities, including waste disposal, commercial transportation, commercial fishing, and mineral-resource exploitation. Those activities sometimes conflict with one another and compromise recreational and aesthetic concerns and the use of resources in continental shelf habitats. Multiple-use impacts on continental shelf habitats are highly variable in space and time, and such impacts, their ecological ramifications, and the prospects for community recovery are difficult to predict.

Added to the variability of multiple-use impacts is the inherent variability of continental shelf habitats in abundance and distribution of dominant species in time and space. The structure of any ecological community is a product of the processes that determine the distribution and abundance of component populations. These patterns of distribution and abundance result from the integration of several things, including:

- Relative availability of important resources.
- Recruitment and differential mortality resulting from

  —species interactions, such as predation and disease,
  —physical disturbance, and
  —physiological stress.

- Direct and indirect effects on communities, including those of contaminants in the food chain.

Natural variability on both spatial and temporal scales determines the detectability of an ecological effect. The problem of detection is complicated by the spatial and temporal covariation of many variables. What appears to be a statistically significant decline in a biological variable during a period of several years of anthropogenic activity (such as OCS oil and gas exploration) might no longer be significant when autocorrelation is taken into account (see Sissenwine and Saila, 1974, for an example). The characteristic scales of natural variability differ in different organisms and processes. Whereas benthic communities can appear to be less variable in time and space than pelagic communities over short periods, benthic communities might not be seen as less variable when annual production scales are considered. For comparison, variability can be scaled to specific generation times of individual components of the ecosystem.

The optimal design of an environmental studies program to discern impacts of OCS operational activities must:

- Define what impacts are likely to occur and the temporal and spatial scales of their occurrence.
- Differentiate between such impacts and natural variability.

An optimal program should also require collection and archiving of environmental data and animal and plant specimens as well as information on the nature, scope, and timing of industrial activities to permit retrospective analysis necessary to determine the likely causes of observed changes in the variables being monitored.

Testing Hypotheses

It is normal in environmental monitoring to test for the adverse effects of perturbations. The perturbations of interest here are hydrocarbon-related discharges and perturbations of the marine and coastal environments. The natural variability of ecological systems makes the effects of human-caused perturbations difficult to detect. If the null hypothesis is that there is no effect, and that null hypothesis cannot be rejected, then the power of a test (i.e., the probability of detecting an effect of a specified size that is present) must be known. If no effect is detected and one is to interpret the test result, one must know how small an effect *could* have been detected. For example, if a test for increased mortality of some benthic species shows no effect, one needs to know what increase *could* have been detected; if a mortality increase of 50% could not have been detected, then the test has low power. Because of natural variability and other factors, tests for the effects of pollutants in nature often have low power.

Power can be increased by increasing sample size or increasing accuracy of detection; both are usually expensive. It is important to decide, in monitoring, how big an effect is "serious," so that the test can be designed with appropriate power. A test with insufficient power to detect a "serious" effect might be relatively inexpensive, but it could be worthless.

An alternative approach is to use a different null hypothesis. This will not affect sampling design, but might affect the outcome of statistical tests and decisions based on those tests. If the null hypothesis is "there is an effect of size s" (e.g., a 22% increase in mortality), then rejection of that null hypothesis is likely to be much more informative than failure to reject a null hypothesis of no effect. The failure to reject the null hypothesis of "a 22% increase in mortality" also provides greater protection of the resource at risk than the failure to reject the null hypothesis of no effect. The approach suggested here is to assume that something causes damage unless it is shown not to, instead of assuming, as is common, that there is no damage unless damage is shown. Because tests for effects often have low power, real effects often fail to be detected until they are quite serious. The current approach, generally used, has led to serious losses, e.g., of fish stocks, of air quality, of water quality, of wetlands, and of diverse other habitats.

Different Approaches for Different Species Groups

The roles of the allocation of important resources and of survivorship have received most of the attention of ecologists who study pelagic and benthic communities; in contrast, the causes and ramifications of recruitment phenomena have received most of the attention of fisheries biologists. Studies of birds and mammals have emphasized descriptions of individual behavior, distribution, and population parameters. The difference in focus is probably because benthic systems and the various vertebrate populations are amenable to different types of approaches to investigation. Important progress has been made in the last decade as ecologists have started to integrate their own research programs with programs directed at an understanding of physical processes and biogeographic phenomena. But much work remains to be done to address the processes affecting natural variability of marine populations, to identify the effects of disturbance (natural and anthropogenic) on such populations, and to define patterns of recovery after disturbance. Thus, to understand the impact of anthropogenic activities on components of continental shelf habitats, we need to define the mechanisms of resistance, elasticity, and recoverability of such communities, as well as the various successional pathways in operation within the many assemblages of pelagic and benthic species.

The past decade has seen considerable advances in both our understanding of the potential impacts of OCS development (Boesch et al., 1987) and the design of sampling programs that are suitable for testing hypotheses and distinguishing between anthropogenic effects and natural variability (Green, 1979; Carney, 1987; Clarke and Green, 1988). Even with those advances, however, prediction of broad-scale ecological consequences of anthropogenic activities, such as OCS development, is a highly uncertain process.

STUDIES OF MARINE BIRDS, MAMMALS, TURTLES, AND ENDANGERED SPECIES

Selection of Species for Study

Because of legal requirements in the ESA and MMPA, and the high valuation placed on them by the public and the perception that they are at especially high risk, marine birds and mammals and endangered species (including marine turtles, as well as endangered marine birds and mammals) have received special focus in the ESP. Specific concerns are that those groups have been adversely affected in the past directly by sedimented and floating oil and other activities associated with hydrocarbon development in the marine environment and indirectly through effects on the food chain. Not all those species are equally valued or at equally high risk, however, and it is not possible to study them all. A rational study plan should allocate scarce resources for study so as to maximize the value of the information obtained.

Species must be selected whose status can also serve as an indicator of environmental change. Among the marine birds and mammals and endangered species, selection of species for study should take account of several criteria:

- *Representativeness.* To the extent feasible, species selected for study should include representatives of various geographic regions, of various oceanographic regimes, of various foraging types (e.g., among birds, aerial feeders, surface feeders, plunge divers, underwater pursuers, and bottom feeders), and of various morphological types (e.g., bare-skinned versus furred mammals).

- *Vulnerability.* The species selected for study should include those judged relatively vulnerable to the effects of OCS activities (e.g., birds that swim at the surface of the water while foraging and hence are vulnerable to oiling), as well as some that are less likely to be affected and might be able to serve as controls for other environmental variables when impacts of OCS activities are judged.
- *Rarity.* The species selected for study should include species that are endangered, rare, or localized and hence that are at risk of severe population effects even if impacts are localized.

Within a species selected for study, geographical populations or breeding colonies should be selected for study according to the following criteria:

- *Representativeness.* To the greatest extent feasible, the populations selected for study should include populations that represent different ecological circumstances, e.g., large and small breeding colonies, dense and sparse feeding aggregations, inshore and pelagic locations, and central and peripheral parts of a range.
- *Ease of Study.* Subject to all the other considerations listed above, it is obviously desirable to select populations or colonies that are easy to study (e.g., species that occur in accessible places, are easy to see and identify, are easy to mark and trace, are tolerant of disturbance, etc.). Locations where representative populations of several species can be studied together have many advantages.

Distribution and Abundance

The principal goal of inventories done by the ESP is to map the seasonal distribution and abundance of the species at risk. That information is necessary for three purposes: to delineate the biological resources at risk, to identify places and times when populations are especially vulnerable to local impacts, and to provide a historical record for measurements of change. Although inventories should focus on the species selected for detailed study, useful information can sometimes be gathered simultaneously on many other species. However, at other times it is inappropriate to combine surveys. For instance, the altitudes appropriate for aerial surveys of birds are not appropriate for turtles and even less appropriate for cetaceans. Ideally, these early studies would lead into monitoring of selected sites so that natural rates of change and processes could be documented before oil is produced.

Ecological Processes

Information on distribution and abundance is necessary as the basis for estimation of risk and impact assessment, but it is not sufficient for either. Some information on ecological processes themselves is necessary for predicting the consequences of OCS activities on populations and identifying the causes of observed changes in populations. This section summarizes four types of ecological information that are required for those purposes.

Relationship of Distribution to Oceanic Features

Estimation of risks to vulnerable species requires calculation of the probability that individual members of the species will encounter and be affected by oil spills (or other adverse consequences of OCS activity). That requires prediction of the distribution and numbers of members of vulnerable species in relation to hypothetical oil spills and knowledge of possible direct and indirect effects. However, the distribution of marine birds, mammals, and turtles is typically very patchy and information is not complete, so there is a large variance in these predictions. Improved understanding of the factors that control the patchiness in distribution of marine species would result in improved predictions of the damage from specific activities. It requires study of the relationships between the distribution of marine species and oceanic features on various scales (Hunt and Schneider, 1987; Winn et al., 1987). On the largest scales, the distributions of individual species are related to broad physical and chemical oceanic characteristics—such as temperature, salinity, and nutrient concentrations—and to the abundance of prey species, which themselves depend on these oceanic characteristics; seasonal distributions and migrations of marine species are related to seasonal changes in temperature, insolation, ice cover, and food availability. On smaller scales, distributions are related to such oceanic features as eddies, fronts, upwellings, and (in the breeding season) the proximity of islands or other breeding sites. Many marine species are social feeders and breeders and aggregate in response to the sight of other organisms (of their own or other species) actively feeding (Hoffman et al., 1981). The timing of feeding aggregations depends on the behavior of the prey; temporal variability in distribution on larger scales is difficult to study, and factors controlling it are poorly understood.

Four types of study are required to understand the relationships between the distributions of marine species and oceanic features: statistical characterization of the variability of distributions in space and time; correlation of the distributions with oceanographic features; study of the behavioral and trophic characteristics that underlie the correlations (see below); and modeling of the relationships (discussed near the end of this chapter). The four types of study themselves have conflicting requirements: the first requires extensive, periodic, systematic surveys; the second requires integration and coordination with studies conducted by scientists in other disciplines; the third requires focused, detailed studies of selected individuals and groups; and the fourth requires systematic, comparable data from the other three. Successful study of ecological relationships will therefore require especially careful planning and integration of studies conducted in different disciplines, at different times and places, and by different methods.

Trophic Relationships

Information regarding trophic relationships—including diets, food webs, foraging methods, predator-prey interactions, and energy transfer—is important for estimation of risk for several reasons. First, foraging methods often have an important influence on vulnerability; for example, birds that swim at the surface between dives for prey are disproportionately vulnerable to floating oil (Bourne, 1976). Second, the distribution and behavior of prey species are important in forming the patterns of distribution of predators that were discussed earlier (Schneider and Hunt, 1984). Third, the impact of OCS activities on prey species, competitors, or predators might affect some species indirectly; understanding of indirect effects will require knowledge of trophic relationships. Fourth, energy flow is important in population dynamics, including recovery times (Ford et al., 1982). Finally, trophic relationships are often important in natural variations in reproductive success—variations that might erroneously be ascribed to OCS activities if their causes are not understood (Ainley and Boekelheide, 1990).

Population Processes

OCS activities can kill or injure mature birds or mammals or impair their reproductive success. Some local effects might be concentrated in a single breeding population, but OCS activities can affect breeding stocks over a large geographic area. Knowledge of migration and dispersal is needed to assess the potential geographic scope of impacts, especially those occurring outside the known breeding season.

Identification of the population consequences of mortality or reproductive impairment requires knowledge of the dynamics of the populations affected. Most marine mammals, birds, and turtles are long-lived and have low reproductive rates and overlapping generations; some have mature individuals that do not breed every year. Development of models that could be used to predict the effects of OCS activities on populations of those species requires knowledge of several population characteristics, including age-specific mortality and fecundity, emigration and migration rates, and numbers of breeding and nonbreeding adults (e.g., Ford et. al., 1982). The effect of frequency of environmental perturbations on populations with different life histories should also be considered. Because of the large time scales of population processes in marine birds and mammals, long-term studies (often exceeding 20 years) are needed to measure such characteristics (Nisbet, 1989). These models could also identify the extent to which low-frequency natural perturbations influence population processes.

Community and Ecosystem Processes

Marine birds, mammals, and turtles interact with each other and with other species and other components of the environment. Interactions occur on a wide variety of spatial and temporal scales and lead to fluctuations in the distribution, size, structure and vital rates of populations. The interactions are complex and difficult to understand, so population fluctuations are difficult to interpret and predict. Understanding the fluctuations is one of ecology's central problems. However, within the context of the ESP, it is important to determine the most important community and ecosystem processes that are vulnerable to perturbation by OCS activities. That task requires both field studies of interactions at the community and ecosystem levels and the development of models to describe the interactions. The models serve several functions; e.g., they help in clarifying questions and directing field studies to the most critical measurements of population processes and they help in predicting population responses to specific perturbations. Such models are necessary if effects of OCS activities (other than large, localized kills) are to be identified or predicted against the background of natural fluctuations or the effects of other human activities such as fishing.

Specific OCS Impacts

Effects of External Oiling

Marine birds, mammals, and turtles can encounter oil while swimming at the surface of the water, while diving or when they come ashore on oil-coated beaches, rocks, or other substrates. External oiling may also affect terrestrial species that encounter spilled oil in the intertidal zone or forage on oiled carcasses. Even if the distribution, movements, and characteristics of spilled oil can be predicted reliably, prediction of the numbers of animals likely to make external contact with the oil requires several other types of information: knowledge of the seasonal distribution and abundance of each species in the area and knowledge of the behavioral characteristics of each species (e.g., swimming at the surface or hauling out on beaches) that would affect the likelihood of their encountering oil. The likelihood that an animal that encounters oil will die as a consequence depends on many factors—the degree of contact, characteristics of the species, characteristics of the oil, environmental temperature, etc. When an oil spill actually occurs, mortality of birds or mammals is often assessed according to number of oiled animals that come ashore; such assessments require knowledge of the behavior of oiled animals (e.g., the tendency of birds to swim ashore when stressed or the probability that oiled carcasses will remain afloat long enough to drift ashore), as well as of drift trajectories.

Toxic Effects of Ingested Oil and Other Physiological Effects

Although lightly oiled birds and mammals might not succumb to the direct effects of external oiling, they could be affected by oil ingested during feeding, preening, or grooming, or absorbed through the skin or by inhaling toxic vapors (Geraci and St. Aubin, 1987); reproduction of birds and turtles can be affected by oil that reaches their eggs (King and Lefever, 1979; Ainley et al., 1981; Lewis and Malecki, 1984; Parnell et al., 1985; and Fry et al., 1986). Several studies have shown that birds that ingest crude oil can develop persistent hemolytic anemia, which would compromise their survival in the wild (Fry, 1987). Other studies have shown that ingestion of oil impairs growth, osmoregulation, and other physiological functions in young birds (Peakall et al., 1980, 1982, 1983; Fry et al., 1986). The significance of those and other toxic effects is likely to depend on the degree of oiling, characteristics of the species, and characteristics of the oil. All those factors need to be taken into account in estimating risk.

Trophic Effects

In addition to direct effects on animals that come into contact with oil, OCS activities might affect birds, mammals, and endangered species indirectly, by changing or contaminating populations of their prey or of predators. Hypothetical examples of such effects include effects on populations of zooplankton, fish, or benthic organisms that are used as food by birds or mammals and effects on populations of predators that may otherwise control populations of marine birds and mammals. Although trophic effects of those types are of great theoretical interest, the panel is unaware of any published studies that have demonstrated the occurrence of such effects in response to oil spills or other OCS activities. Their potential occurrence and importance could be demonstrated by modeling of trophic interactions and measuring or modeling effects on the trophic level of interest.

Disturbance

Many OCS activities—including construction, seismic exploration, and boat and helicopter traffic—result in noise and other stimuli that are potentially disturbing to sensitive wildlife. In addition, the growth in human populations and development of roads, ports, and airfields that follows OCS developments might result in increases in hunting and other potentially disturbing activities. Known effects of such disturbance include abandonment of breeding colonies of birds and mammals and changes in migration routes and feeding areas. In such cases, displacement may result in higher densities in adjacent areas, and have effects beyond the area abandoned. In other cases, there may be suitable alternative habitats so that the only practical effect is a shift in distribution. However, some species can adapt rapidly to predictable human activities, so the effects of disturbance are not necessarily uniformly adverse or proportional to intensity (Schreiber and Schreiber, 1980). Assessment of the potential effects of noise and disturbance must be carried out case by case, and results of short-term studies are not necessarily predictive of long-term effects.

Other Potential Effects

Other potential effects of OCS activities on birds, mammals, and endangered species include degradation of salt marshes by construction of pipelines and disposal areas, changes in tidal currents resulting from construction of islands and causeways, and secondary effects of residential development. Polar bears may be attracted to industrial activities and killed to defend human life or as a result of increased hunting pressure (Lentfer, 1990). Industrial activities can also disturb polar bear denning habitat, and there is the potential for cumulative effects on migratory species, as well as unforeseen effects that could be discovered through monitoring. Any such effects must be assessed on a site-specific basis, and the types of activity that are likely to occur, characteristics of the local environment, and sensitivity of local species must be taken into account.

CHARACTERIZATION OF BENTHIC ENVIRONMENTS

Long-term impacts of OCS development are most likely to occur in the benthic environment from chronic discharges during development and production and from the accumulation of contaminants in sediment reservoirs (NRC, 1985; Boesch et al., 1987). Detecting changes in contaminant concentrations in benthic environments resulting from OCS oil and gas development will require a better understanding of the sources of contaminants (including other anthropogenic sources) and the processes that affect their fate in benthic environments. Such a task requires a combination of generic experimental approaches, observational studies, process-oriented studies, and regionally focused field assessments to establish realistic exposure scenarios (in both space and time) and to distinguish the effects of OCS activities from natural variation (Boesch et al., 1987; Capuzzo, 1987; Carney, 1987).

Ease of sampling is an obvious feature of benthic organisms that makes them useful in answering recruitment questions. Many are relatively sedentary (and consequently can be exposed to pollutants for long periods) and can be resampled over time. Coastal benthic habitats are heavily exploited for biological resources, including finfish, shellfish, echinoderms, and kelps. Because a large proportion of the U.S. population lives near the coast, human impacts are intense and well documented. Thus, the ability to know is coupled with the need to know.

Benthic systems are thus useful in understanding how populations and communities change in the sea. One way to assess present capability is to ask how well, using benthos, we can predict and observe the full recruitment process from the production of new individuals (birth) through individual survival to successful reproduction and renewal of the cycle. Besides assessing the roles of dispersal and initial settlement, one must ask how well the crucial intervening growth and survival to the next reproductive event can be predicted. Understanding the acquisition of nutrients by the suspension and deposit feeders that dominate and characterize the seafloor has assumed a major role in such prediction, because these organisms both spend and gain much of their resources for growth and reproduction in feeding. Effort in understanding benthic feeding processes appears well spent also because the same physical processes that deliver food to the benthos deliver larvae as well.

Carney (1987), in his review of OCS benthic monitoring programs, concluded that none of the studies conducted before 1985 could define *a priori* what they were looking for; therefore, they could not use optimal design techniques. Although some intense point-source impacts of anthropogenic activities might be unambiguously recognized without a need to understand the sources of natural variability in benthic processes, detection of most anthropogenic activities requires an understanding of both the magnitude and the natural causes of variation in the absence of human intervention. Whenever an experimental effect is to be detected, it is necessary to know the magnitude of control or reference ("baseline") variability in what is being tested. Without an understanding of the processes that cause natural variation, the mechanism of human influence is not likely to be established. Knowledge of mechanisms helps to confirm causation and is necessary for prediction under new conditions. It is difficult to establish causation in the presence of confounding variables, and so it is probably necessary to understand the processes that control natural variability to detect the more subtle impacts of human activities that are pervasive over larger areas or longer periods.

As Carney (1987) documented in great detail, it is insufficient for a monitoring program to document an effect without also providing an understanding of the mechanistic processes that produced it. First, an appreciation of the mechanism makes more credible the conclusion that an observed pattern was in fact caused by human intervention in the natural ecosystem. In the absence of a mechanistic explanation, causation remains in doubt and the observed pattern may be the result of spurious correlation. Second, a phenomenological understanding of mechanisms is necessary for generalization, extrapolation, and prediction based on the observed results. The transfer of results from one system or geographic region to another will be made more reliable if underlying mechanisms are understood.

Establishing mechanisms in benthic processes requires that well-designed field or laboratory experiments complement the monitoring process. Many variables are inextricably confounded in nature, and their effects can be separated only through experimentation (Carney, 1987). Mesocosms, flumes, or small experimental setups are potentially important in making possible the observations of organism behavior and various biological interactions that are necessary for a complete understanding of benthic processes. Mesocosms and other laboratory systems must be used appropriately to prevent laboratory artifacts from confusing the results (Capuzzo, 1987; Underwood and Peterson, 1988). Although laboratory and mesocosm studies are especially constrained to processes on small spatial scales, they provide a valuable link between field investigations by defining the biological and geochemical factors responsible for contaminant transport and effects. Furthermore, only through careful experimentation can complex interactions, such as nonadditive effects and higher-order interactions among variables, be detected and appreciated.

Understanding how anthropogenic activities, such as oil and gas exploration and development, affect benthic organisms on the OCS requires collaboration of biologists with physical oceanographers and biogeochemists. Without knowledge of physics, the scales and boundary conditions of important transport processes cannot be determined. Without knowledge of geochemistry, the fates of materials and rates of transformation cannot be established. Those components of a complete monitoring study cannot be designed and conducted in isolation from biology. An integrated study of processes that affect benthic organisms is necessary for unequivocal demonstration of the anthropogenic impacts on benthic populations. With regard to specific, subtle, pervasive impacts of anthropogenic activities, study of physical and geochemical processes is necessary for deciphering the mechanisms of natural biological variation in benthic populations.

The benthic zone of the inner shelf from the beach or surf zone to a depth of about 30 m is poorly studied but crucially important because it is here where oil spills will encounter land. An understanding of the subsequent physical dynamics of transport, geochemical transformations of the hydrocarbons and other petroleum compounds, and biological impacts is required for a responsible and rigorous set of predictions of vulnerability and effects. In addition, understanding physical effects of perturbations, such as the effects of channelization on Louisiana's wetlands, also requires an integrated study of physics, chemistry, and biology. This zone of the ocean is too shallow for access by traditional oceanographic vessels and too far away and dynamic to be accessed easily from land. It has been insufficiently studied despite the complexity of its dynamics and its importance. As an indication of the need for process understanding of this zone, the NSF-nurtured research initiative on coastal oceanography (CoOP) has prepared and NSF has released an RFP (Joint Oceanographic Institutions, Inc., 1991) for interdisciplinary oceanographic studies, identifying this system as one of the two top priorities for immediate attention.

FISHERIES

Assessment of the effects of OCS activities on fishery resources and ecosystem processes is constrained by the same difficulties as discussed above—the difficulties in predicting and detecting effects within the natural background of high spatial and temporal variability. MMS has a responsibility to assess the effects, regardless of the difficulties involved, but cannot be expected to make predictions of fisheries recruitment and productivity when these topics still confound fishery scientists. Assessment of OCS impacts requires a strategy that provides information to support reasonable short-term decisions based on current knowledge about how fishery resources and ecosystems respond to perturbations. The strategy must also provide a better long-term understanding of variability, ecosystem processes, and robustness of natural systems.

The most basic information that should be considered for assessing the potential effects of OCS activities is the spatial and temporal distribution of harvested species and key ecosystem components. Life-history patterns should be understood in sufficient detail to identify critical habitats, whose degradation can jeopardize populations. Spawning grounds, areas of concentration of eggs and larvae, nursery grounds, and migratory routes are particularly important.

One problem peculiar to assessment of fishery resources (stock assessment) is the great variation in recruitment of the species. Natural variability in reproductive success of the species makes it difficult to determine the relationship between population size and recruitment, and thus predict the size of the population a few years in advance and to assess the long-term capability of a population to compensate for stress (caused by overfishing, OCS activities or other human activities, or the interaction of multiple natural non-human and human forces). Numerous models are used to estimate the effects of fishing on fishery resources (Ricker, 1954).

OCS activity—which could be analogous in some respects to fishing—potentially has a chronic effect on a population as a result of effects on growth, natural mortality, and reproductive variables or as a result of effects on prerecruit survival. It might be useful to express the effect of OCS activity on a population in the same manner as fishing mortality, so that the vast amount of information on the effects of fishing can be used to help in assessing the potential effects of OCS activity. Traditional fish population-dynamics models can be expanded to account for perturbations other than fishing activity (e.g., Schaaf et al., 1987).

ECOSYSTEM MODELING

Ecological phenomena (e.g., succession, reproduction, feeding, survival, evolution) are characterized by processes that occur at different rates; those rates vary from one place to another. Mathematical models are a component of ecosystem studies that facilitate both understanding of underlying mechanisms and prediction of consequences and can generate new insights into basic systems. No model can achieve the goals of generality, realism, and precision simultaneously (Levins, 1968); for understanding and managing the environment, a variety of models are needed. In addition, problems of scale are increasingly recognized as important; development of useful models on one spatiotemporal scale probably cannot provide insights into phenomena operating on other scales. The concept of equilibrium is inseparable from that of scale. The insights from any investigation are therefore contingent on the choice of scale, and there is no single correct scale of observation.

Two major modeling approaches have evolved (NRC, 1990a), both of which are sensitive to the above limitations. Highly descriptive, parameter-rich models incorporate much system detail, but suffer from specificity (lack of generality) and statistical difficulties in estimation of parameters. Simplified models can attain generality, but only at the expense of development of the underlying mechanisms.

MMS has used two broad classes of models to assess the effects of OCS activities: descriptive models, in which observational data are fitted to statistics, and statistical parameters are derived for use in prediction or hypothesis testing; and process models of complex ecological systems, which are constructed from submodels with data derived from process studies. Empirical parameters derived from descriptive models of ecological processes are often used to set parameters for process models, which can then be used to predict the response of the system to external perturbations (e.g., Ford et al., 1982). Models of both types require validation before they can be linked and used this way to predict system responses. Validation of mathematical models is a perplexing problem, because of the natural variability and complexity of marine ecosystems. The need to resolve that problem highlights the importance of conducting long-term, process-oriented studies.

Because complex systems will always have components that are not well understood, conclusions will always depend on the validity of model assumptions, which should be stated explicitly. Similarly, models cannot take account of all components of a system, so conclusions can be valid only if system components not accounted for are constant. Finally, it is important that data used in models be representative of the variables that are being modeled. However insightful a model might be, if it is based on inadequate data, conclusions based on the model's output will be faulty. Indeed, one important use of models is to guide the collection and interpretation of data.

In many efforts to model particular ecological situations, irrelevant details are introduced on the mistaken premise that somehow more detail assures greater truth. In fact, there can be no one "correct" level of aggregation for a given study. If the taxonomic species, for example, is used as the unit of classification, the differences among the individuals within it are automatically ignored. In ecology, functional systems of classification are often preferable to taxonomic ones, and a failure to recognize this relationship can lead to difficulties.

The results of the surveys and process studies discussed in the previous sections will ultimately be used for either of two purposes: to predict the consequences of hypothetical oil spills or other OCS activities, or to interpret and assign causes to observed changes in patterns of distribution and abundance. In either case, observations made at one place and time will be applied to circumstances that prevail at other places and times and that often involve different individuals or even species. Such applications are possible only through the use of models; thus, modeling is an essential element in OCS assessment.

Identification of cause-effect relationships of human activities is difficult, because of the large number of variables in biological systems (Rothschild, 1986). The variability and biological interactions present an impediment to both empirical prediction models and experimental approaches, in that it is impractical to account for all variables. Study designs must incorporate methods to assess both ecosystem perturbations and recovery rates. Statistical methods based on Markov-process models (e.g., Rothschild and Mullen, 1985; Saila and Erzini 1987) are available to estimate how seriously a system has been perturbed and its characteristic recovery time. Those models assume, however, that a system is stationary, and that is often an invalid assumption.

Assuming that models can be constructed to describe or predict the responses of marine ecosystems to perturbations, the perturbations must be characterized. Potentially, OCS activities can perturb marine systems in several ways, such as a direct impact of oil on organisms that encounter it, effects mediated through trophic relationships, effects of noise or other disturbance on sensitive species, and effects on coastal wetlands.

In summary, ecosystem modeling holds the promise of increasing insight and the ability to predict effects. But there are many difficulties along the road. It seems likely that ecosystem models are currently capable of guiding the collection and interpretation of data. However, it appears that more data and validation of models against field observations are needed before ecological and physical oceanographic models can be linked in complex ways to predict the effects of OCS activities on ecosystems.

3

Analysis of the Program

BIRDS

Allocation of Program Effort

The panel has analyzed the allocation of Environmental Studies Program effort among marine regions and categories of study. The eight marine regions are those listed in the section on benthic studies. The studies are divided into seven broad categories, as follows:

- *Colony inventory.* Location and mapping of breeding colonies and estimates of numbers of birds of each species in each colony.
- *At-sea inventory.* Surveys and mapping of distributions of birds at sea, usually based on standardized transect methods.
- *Shoreline habitats.* Surveys of habitats and their use by birds in nearshore, intertidal, and supratidal zones, including studies of distribution, abundance, and feeding of birds in these zones during the breeding season and on migration.
- *Colony processes.* Studies conducted at breeding colonies of phenology, reproductive success, trophic processes, recruitment and age structure, and changes in numbers.
- *At-sea processes.* Studies relating the distribution of birds at sea to physical and biological features of the ocean environment, including prey numbers and distribution.
- *Exposure and effects.* Studies of factors that control direct and indirect exposure of marine birds to oil and physiological and reproductive effects of exposure.
- *Modeling.* Integrative models of the consequences of oil spills, including estimates of contact with bird populations and consequent mortality, physiological, and population changes.

MMS maintains records of the allocation of contracts by administrative region and by lease-sale area, but the Ecology Panel chose to examine allocation of project effort and funds by marine region and by category of ecological study. The allocation developed by the panel was based on a list of contracts provided by MMS. For projects conducted in more than one marine region or in more than one year or covering more than one category of study, the panel allocated project effort according to the following rules:

- One project-year was assigned to each region for every year for which the project was funded.

- For projects involving more than one group of animals (birds, pinnipeds, cetaceans, or turtles), the panel assumed that project funds were assigned equally to each group.
- The panel assumed that project funds were assigned equally to each region and to each category of study listed in the project title or in titles of reports or publications.

It is recognized that these assumptions are imprecise, but they should give a reasonable approximation of the actual allocation of program efforts.

An analysis by the panel of MMS's bird studies shows that the regional allocation of bird-related effort in the MMS program has been extremely uneven. Almost all the program effort was allocated to waters off Alaska (85% of project-years and 67% of program funds) or to waters off California (12% of project-years and 29% of program funds). The large amount of program effort in Alaska was not unreasonable, in view of the large numbers of marine birds that breed there, the relatively poor initial knowledge of these birds, the drilling activity in Alaskan waters in the early years of the ESP, and the high costs of investigation there. A large amount of effort was expended in the Beaufort Sea region, which has a small number of pelagic birds breeding there, but in fact the effort was spent mainly on investigation of shoreline and lagoon habitats, where migratory birds and waterfowl are concentrated and are potentially vulnerable to OCS activities. The allocation in California of 29% of all the program funds allocated to birds appears out of proportion to the small numbers of marine birds that breed in California, but it is not; much of the work was conducted on the numerous migratory and wintering species and on effects studies that could be generalized to other regions.

Essentially no MMS studies of birds have been conducted in the Atlantic regions, although some studies have been conducted by other agencies (e.g., Erwin, 1979 (FWS); Korschgen, 1979 (FWS); Powers, 1983 (NMFS)). Only about 2% of the program's resources were allocated to studies in the Gulf of Mexico. The amounts of effort and funding allocated to the Gulf of Mexico and the Atlantic regions are much smaller than would have seemed appropriate, given the magnitude of existing or proposed OCS activity. The lack of follow-up studies of birds in areas with oil production, i.e., in the Gulf of Mexico and southern California, has made it impossible to learn the long-term effects of OCS production on birds.

The allocation of program effort among the various categories of study appears reasonable. About 31% of program funds was allocated to studies on breeding colonies, including surveys, censuses, and studies of productivity and diet. About 39% of program funds was allocated to studies at sea, mainly on distributional surveys and diet studies during the breeding season. About 17% of program funds was spent on shoreline habitat studies, mainly in Alaska, and about 11% on studies of exposure to and effects of oil. Only 3% of program funds (three projects) was spent on constructing models of effects of oil spills.

Assessment of Results

The ESP provided a major impetus for the study of marine birds in the waters of the United States. It sponsored major surveys of the distribution of seabird colonies and the distribution of birds at sea. Through those efforts, our knowledge of the distribution and abundance of breeding North American seabirds has been greatly increased, particularly in Alaska, for which only sketchy information was previously available. ESP studies of the pelagic distribution and abundance of birds were, with a few exceptions, the first systematic attempts to study the pelagic biology of seabirds in U.S. waters, and they have provided the foundation of our knowledge of the marine biology of seabirds and the data base needed by investigators to pursue more narrowly defined projects, supported by other agencies.

In the pelagic realm, the early ESP efforts led to techniques that are now standard in surveying, data recording, and oceanographic and remote sensing. The studies of foraging distribution and trophic webs greatly increased our general knowledge of seabird pelagic ecology and provided data on which later research would be based.

In contrast, the colony-based studies did not result in the same degree of advancement of a field of study as did the pelagic work. Useful modeling exercises were carried out by the ESP, but it is not clear how lasting a contribution they will make, because of the specialized nature of the models and the apparent lack of follow-through in generalizing, validating, and applying them.

Finally, in toxicology, the ESP has funded the development of excellent new analytical techniques for detecting and identifying hydrocarbon residues and of innovative field studies of the effects of hydrocarbon pollutants. The physiological studies, although narrowly directed at the effects of oil, have increased our awareness of the sensitivity of some native species and of the importance of working with native species in the wild, rather than relying solely on laboratory tests with standard animal models.

The following evaluation provides a more critical analysis of the strengths and weaknesses of the ESP relative to its mandate for environmental impact assessment. In the broad overview, the program supported a wide variety of research endeavors that added greatly to our knowledge of marine birds in a very short period. Most of the knowledge is available in the "gray" literature, and a fairly large amount is becoming available in the refereed literature. The latter body of published material is strong evidence of the accomplishments of the ESP effort.

Selection of Species and Locations for Study

The panel was not provided with any documentation as to the methods or rationale for the selection of bird species or sites for study. Although general planning meetings were held for both the Southern California Bight region (Lavenbin and Earle, 1975) and the Alaska region (NMFS, 1975), they were too general to yield carefully designed plans (see also Bartonek and Nettleship, 1979). The selection of species appears to have been largely at the discretion of the various investigators and to reflect a combination of factors, such as ease of study and scientific interest, as well as potential vulnerability to oil. This mix of criteria seems reasonable; in most regions where there was a substantial ESP effort, the variety of species chosen provided a reasonably good coverage of the most abundant species, the species most vulnerable to oiling, and easily studied species that might be good indicators of local environmental change.

In the pelagic studies, little apparent effort was made to target selected species for study. An exception was the study of shearwaters (*Puffinus* spp.) in Alaska (Guzman and Myers, 1982). Generally, individual investigators singled out particular species for more thorough analysis, e.g., brown pelican, *Pelicanus occidentalis*, in California (Briggs et al., 1981b, 1983a). For the most part, studies were aimed at the investigation of given areas and encompassed all species present. That was usually appropriate, in that the integrated study of marine ecosystems is more likely, as a first cut, to provide a broad understanding of the multiplicity of factors that influence the pelagic distribution and abundance of birds than would the study of individual species.

The allocation of effort in the study of the breeding distribution of birds was on a colony or area basis, rather than on a species basis. Surface-nesting and cliff-nesting species received the best coverage, and burrow-nesting (particularly nocturnal) species received less complete coverage. Nocturnal species are very difficult to count, and the sizes of their populations remain poorly known. To the extent that nocturnal species are potentially very vulnerable to oil pollution, more attention should have been paid to assessing the location and size of their nesting populations.

In the colony-based studies of reproductive and trophic ecology, many factors appear to have influenced which colonies were chosen initially and the selection of species for study. Large colonies, important centers of the population of a given species, and accessibility were considered important. In no region was there a detailed plan at the outset for the coverage of particular species or a particular set of "representative" colonies. However, in most colonies investigated, a mix of species was used, including surface or cliff nesters and species that dive in pursuit of prey (alcids) and forage at or near the surface, often while airborne (kittiwakes, gulls, and terns). Studies of storm petrels, fulmars, and nocturnally active alcids were few and narrowly distributed.

Conspicuously absent from the ESP for marine birds are studies of the several endangered or threatened species that occur in lease areas or habitats adjacent to OCS areas. We found no studies focusing on the short-tailed albatross (*Diomedea albatrus*), cahow or Bermuda petrel (*Pterodroma cahow*), California brown pelican (*Pelecanus occidentalis*) (although aspects of pelican biology were addressed in several California studies), Aleutian Canada goose (*Branta canadensis leucopareia*), snowy plover (*Charadrius alexandrinus*), California least tern (*Sterna antilarum browni*), roseate tern (*S. dougallii*), or the various threatened or endangered salt-marsh-inhabiting species, including some of the subspecies of the clapper rail (*Rallus longirostis*) or the various salt marsh sparrows. If anything, the endangered marine bird species appear to have been avoided as subjects of study in the ESP. In some cases, attempts to direct studies toward endangered species would have been futile, because of the small numbers present in OCS waters (e.g., short-tailed albatross). In other cases, the failure to examine carefully the potential impacts of OCS development on endangered and threatened bird species potentially vulnerable to OCS activities was a serious oversight.

The rationale for the selection of colony sites for process studies and at-sea areas for both inventory and process studies is unclear. For colony process studies, we know of no attempt at the outset to select a representative group of major colonies in each OCS region, let alone in each marine domain, for careful, long-term study. Most colonies in most regions were studied for short periods, 1-3 years, and sometimes for less than one full season. This dispersed, fragmented approach dissipated resources and led to a diversity of data, most of which are too incomplete to provide a clear picture of the degree of natural variation in the system. After the first year or two of the program in each region, it would have been appropriate to select, in cooperation with other concerned state and federal agencies (U.S. Fish and Wildlife Service, and various state fish and game departments), the one or two most important colonies in each ecological domain on which to focus long-term attention (for the duration of the OCS program). An extremely productive effort of that sort, which took place in the fall of 1984 in Alaska for studies in the Bering Sea, included not only federal and state scientists but others, as well. However, this and later efforts came almost 8 years or more too late for influencing the major ESP efforts in Alaska. We are unaware of any equivalent cooperative planning process that was used to assess progress and to develop recommendations for priorities for future seabird work in any other OCS region.

The sites for pelagic inventories of marine birds and pelagic process studies were decided more by the dictates of other programs in charge of ship use than by needs for adequate coverage to discern where and why marine birds might congregate at sea. Relatively little work was devoted to studying the distribution of vulnerable species (e.g., alcids) foraging near major colonies; efforts at the Pribilof Islands (Hunt et al., 1981a), at Kodiak Island (Gould et al., 1982), and in the Southern California Bight (Hunt et al., 1979) were exceptions. For other areas, MMS obtained few or no data on where birds from important colonies might be expected to concentrate their foraging. Such data are essential for developing an appropriate environmental impact statement (EIS) for the protection of critical foraging areas, and for the protection of the colonies from spilled oil. Birds are not distributed randomly but are aggregated with respect to physical structures. Two major instances of aggregation in predictable locations are in the vicinity of fronts and where currents impinge on bathymetry of high relief, causing prey to aggregate and become more available to birds. To the extent that such areas are near colonies or are along migration routes, it can be expected that large numbers of birds will be concentrated in small areas. MMS should focus on process studies within foraging range of colonies and in known major migration routes to determine where predictably large concentrations of birds will occur.

Colony Inventories

Inventories of seabird colonies are now available for most of the coasts of the coterminous United States. The inventories were sponsored by MMS in Alaska (Sowls et al., 1978) and California (Sowls et al., 1980) and by the Fish and Wildlife Service (FWS) in Washington and Oregon (Varoujean, 1978), the Gulf of Mexico (e.g., Keller et al., 1984), and the Atlantic coast (e.g., Erwin and Korschgen, 1979). Additional surveys have been sponsored by the U.S. Army Corps of Engineers (e.g., Buckley and McCaffrey, 1978; Chaney et al. , 1978; Peters et al., 1978; Schreiber and Schreiber, 1978). Together, the atlases and reports based on those surveys are an excellent source of information on areas where breeding seabirds were concentrated and where densities of seabirds were low, at least at the times when the surveys were conducted. However, MMS was unable to furnish the panel with maps depicting distribution and abundance of breeding birds; the lack of such maps limits the ability to retrieve information on birds at risk in the event of a major OCS oil spill or for use in planning or running quantitative oil-spill risk models. Recently, however, a computer mapping and analysis system was developed by FWS and NMFS for analyzing the spatial and temporal distribution, abundance, and life history of breeding colonial seabirds on the west coast of North America from California to Alaska. The data base for this system includes information from MMS-sponsored inventories (FWS/NMFS, 1991).

Although the panel considers the available knowledge of colony locations and sizes adequate for assessing the potential for damage from OCS activities (i.e., as the basis for estimating risk), the available data are inadequate as the basis for assessing change (including measurement of impacts of actual events). First, the methods for estimating population size within colonies have been crude at best. Many colonies were surveyed only from a boat or from a passing aircraft. The surveys established where large numbers of surface- and cliff-nesting species were, but gave little information about burrow-nesting, particularly nocturnally active species. Estimates of numbers in the largest "supercolonies" are particularly uncertain. Although marked plots have been established in a small number of breeding colonies in Alaska (mostly by FWS, independently of the ESP), the relationship of numbers within these plots to colony size and regional populations is poorly understood. Hourly, daily, seasonal, and annual changes in numbers within study plots and within colonies are relatively large and are difficult to control for (Wanless et al., 1982). Thus, baseline measures of sample or regional populations are imprecise. Second, most of the regional surveys have been conducted only once. Movements of birds between colonies would confound attempts to infer regional trends from sample counts, but these movements have not been investigated for any species in the MMS program. Finally, counts are available only for breeding birds: the proportions of prebreeders and nonbreeders are unknown. In virtually no cases have surveys been accurate enough or counts been repeated enough to provide the means to detect any but the largest or most sustained changes in population size. The few exceptions to that generalization are long-term studies of individual species funded by agencies other than MMS (see Hunt, 1987; Nisbet, 1989).

At-Sea Inventories

Techniques for the at-sea survey of birds from both ships and aircraft were developed at the outset of the ESP (e.g., Briggs et al., 1981a). The newer surveys improved on many studies done elsewhere, in that they used a format that reduced (but did not eliminate) the problems of differential detectability of species and variations in visibility related to observers' height above the water and weather conditions. Aerial remote sensing of oceanographic characteristics coupled with observations of pelagic birds constituted an important method not only for describing bird distribution, but for testing hypotheses concerning the mechanisms responsible for the patterns observed (Briggs et al., 1987). The latter information is important for understanding whether the patterns observed are likely to be regular and frequent.

The surveys of the distribution and abundance of marine birds at sea varied greatly from one marine region to another in spatial and seasonal coverage. No up-to-date maps showing the distribution of sampling effort by marine region and by season or maps of seabird distributions are available from MMS, although maps showing the areas covered by specific studies are available in the final reports of completed studies. Most parts of the continental shelf off Alaska received at least some coverage, particularly during the summer season. The Alaskan studies provide a good general overview of seasonal shifts in the distribution of birds and a preliminary indication of spatial patterns of abundance (Hunt et al., 1981b; Gould et al., 1982).

Coverage of the coast and the waters off California has been excellent, and both seasonal and spatial patterns of distribution are known (Briggs et al., 1981a, 1983b, 1987). No MMS studies of pelagic distributions of birds off the Oregon and Washington coasts have been published, although a study of this region is to be completed in 1991.

In the Gulf of Mexico, surveys of the distribution of marine birds have provided poor coverage of the area and only fair coverage of seasonal patterns of abundance. A pilot study (Fritts and Reynolds, 1981) provided aerial coverage of four small areas in August and December 1979, and a followup study covered these areas with a series of seven surveys between June 1980 and April 1981 (Fritts et al., 1983). In all, the study involved approximately 45 days of flying; about half the flights were at an altitude suitable for bird observations (91 m) and about half at a higher altitude (228 m), more suitable for spotting marine mammals.

There appear to have been no MMS-sponsored surveys of marine bird distribution along the southern and central Atlantic coasts or for Georges Bank or the Gulf of Maine. However, much of this area has been surveyed by other agencies (e.g., Powers, 1983 (NMFS); Brown, 1986 (Canadian Wildlife Service)). Although sampling methods were standardized for MMS-sponsored studies on the Pacific coast and in Alaska, different methods were used in the surveys of the Gulf of Mexico and Atlantic waters. The lack of uniformity of data collection and storage prevents the construction of a nationwide data base, although some regional data bases are being maintained. To the panel's knowledge, data from the Gulf of Mexico and Atlantic coast have not been incorporated into an MMS data base, from which they could be retrieved (e.g., for real-time response to an oil spill or for planning purposes, such as inclusion in a quantitative oil-spill risk model).

Examination of the available data on pelagic distributions of birds reveals that data on bird densities (transect counts) for relatively large areas consist of small numbers of counts with high among-count variances (e.g., Hunt et al., 1982). Even in the areas with the best coverage (Alaska and California), the data are useful only to provide a general picture of the patterns of spatial and seasonal abundance and hence to identify general areas in which bird populations might be at special risk. Because the samples are small and the variance-to-mean ratios (reflecting the patchiness of bird distributions) are high, the data are, for the most part, statistically inadequate to provide a reference against which to measure change.

Shoreline Habitat Inventories

MMS-funded surveys of inshore waters and intertidal and supertidal areas are limited in coverage and distribution. In Alaska, there have been extensive surveys of habitat availability (Arneson 1980), but only fragmentary studies of use of the habitats by birds. Parts of the Beaufort Sea coast have been well studied (e.g., Connors et al., 1981; Johnson, 1983), as have parts of Norton Sound (Drury et al., 1981), the Yukon Delta (Eldridge, 1987), the north coast of the Alaska Peninsula (Troy and Johnson, 1987), and some areas in the Gulf of Alaska where major migratory stopovers have been identified (reviewed in DeGange and Sanger, 1987). For the most part, however, use by birds of the coastal zone of Alaska remains poorly known because of extreme logistic difficulties. In the 48 states, MMS has provided partial support of beach and inshore bird surveys in the Southern California Bight and in a small portion of the Gulf of Mexico, and other agencies have sponsored beach surveys in central California. Most coastal areas remain unsurveyed.

MMS has sponsored studies of the distribution of beach-cast carcasses of oiled birds in California (e.g., Stenzel et al., 1988) and on a small portion of the gulf coast of Texas, but few elsewhere. Recent studies of the proportion of oiled carcasses that actually reached the beach indicate a great deal of short-term variability in the likelihood that a carcass would reach the beach and be found (Page et al., 1982). Without extensive concurrent data on winds, currents, and carcass flotation, beached-bird surveys are of little value as measures of mortality and are of only modest value as a reference for future monitoring.

Colony Process Studies

Process studies conducted on colonies include measurements of phenology, diet, chick growth, and productivity; variations in these characteristics can be correlated with environmental factors, such as temperature and prey availability. Measurement of additional characteristics—such as survival, age at first breeding, recruitment, and dispersal—can then provide the basis for construction of models of population structure and of the relationship of population change to environmental factors. Because most seabirds are long-lived, total population size and colony numbers are less sensitive to short-term changes in the environment than are process measures, such as clutch size, chick growth rates, and productivity. Process studies are therefore essential if effects of local or short-term environmental changes are to be detected.

Colony process studies can provide information on the natural range of variation in system characteristics, an early warning of potential problems, and a means of detecting and predicting changes caused by environmental factors other than OCS activities. Properly executed, they can provide a historical record against which to measure change. They can also be useful in increasing our understanding of the environmental correlates and natural causes of changes in reproductive and trophic biology of selected species. Colony process studies are essential as sources of data for constructing predictive models of impacts of OCS activities. Colony studies are unlikely to provide the basis for attributing specific observed changes to the effects of OCS activities, but might be useful in providing alternative explanations when changes are observed.

To be of greatest value, colony process studies need to be carried out over long terms and be incorporated into monitoring programs. Within the ESP, however, most colony process studies have lasted only 2-4 years. In Alaska, colonies of various species have been studied for longer periods with support from MMS in some years and from FWS in others (e.g., Cape Lisburne, Pribilof Islands, and Prince William Sound). In California, MMS supported one 3 year study in the Southern California Bight that was continued with funds from other sources. In central California, one 19 year study at the Farallon Islands supported by non-MMS funds is going on now (Ainley and Boekelheide, 1990).

In the panel's opinion, the colony process studies conducted under the ESP yielded much less valuable results than could have been obtained with better allocation of the same funds. The lack of a coherent plan and of a commitment to long-term studies at strategic locations at the outset has resulted in a large number of studies of short duration, many of which cannot be interpreted or integrated into an overall understanding of colony processes. Many of the studies were terminated 5-10 years ago; in the absence of recent followup, it is not clear whether the early results can be used to predict or evaluate impacts of OCS activities. Properly planned and executed, colony process studies could have been invaluable in identifying short-term changes and in correlating them with environmental changes. Without continuing studies, it will be difficult or impossible to identify natural causes of observed changes and hence to rule out OCS activities as causes of these changes. The ESP made a good start on thorough process studies at several colonies; the program is deficient in that it did not follow up this good start by shifting efforts at some of the sites to a continuing monitoring program designed for the duration of OCS activities in the selected areas, as is required by OCSLA as amended in 1978.

At-Sea Process Studies

In the context of the ESP, the primary function of at-sea process studies is to aid in understanding the observed patterns of avian distribution and abundance. Such understanding, based on elucidation of underlying processes, should help in the prediction of the degree of aggregation of at-sea populations and prediction of the locations of aggregations in specific circumstances. Process studies should integrate information across trophic levels and should ultimately be grounded in the understanding of physical and biological processes in the ocean.

Most at-sea process studies of marine birds conducted in the ESP are of only limited value in serving those functions and were not designed to do so. In Alaska, most at-sea process studies investigated food habits of birds, but did not integrate the resulting information with physical data or data on prey availability. However, in the California studies, information on physical processes and chlorophyll concentrations obtained with remote sensing was combined with shipboard collections of data on the foods available and taken by birds in areas of seabird abundance to provide a picture of why particular species concentrated where they did (Briggs et al., 1987). The panel knows of no MMS-funded studies of the effects of marine processes on seabird distribution and abundance other than those in Alaska and California.

In nearshore and shoreline habitats, data were gathered on the foraging of seabirds and shorebirds along the Beaufort Sea coast (Connors et al., 1981) and in the coastal regions of the Gulf of Alaska (Senner, 1979). Those studies provided useful information on feeding sites, foods, and fat deposition of migrating shorebirds and yielded an assessment of the importance of the studied habitats to the successful completion of migration by the species. Studies of the use of coastal lagoons by waterfowl also provided valuable information on the use of the specific lagoons for the successful migration of the species and populations that used them. The process studies in the intertidal zone have yielded data essential for assessing the vulnerability of areas used as staging areas by important populations of shorebirds and waterfowl.

Effects Studies, Modeling, and Estimation of Risk

The MMS program has put only a small percentage of its seabird program effort into investigations of the potential effects of OCS activities on birds. The studies that were funded included investigations of the incidence of oil ingestion by storm petrels (Boersma, 1986) and of reactions of birds to oil and incidence of oiling (Varoujean et al., 1983), field studies of the effects of ingested oil on reproduction in alcids and petrels (Fry, 1987), studies of recovery rates of two species of birds on the Pribilof Islands (Ford et al., 1982), and a series of risk-assessment models, primarily for the Southern California Bight (e.g., Ford, 1985). Studies of the effects of the *IXTOC-I* oil spill on the coast of Texas showed decreased use of beaches by shorebirds and fouling of plumage and accumulation of globs of tar on the feet of gulls, terns, and shorebirds, including threatened and endangered species (A. Amos, Texas A & M Marine Station, pers. commun., 1991). On the whole, those efforts appear to have been useful. The panel considers the opportunistic use of wild species of seabirds in the field for toxicity studies to be a marked improvement over laboratory studies of waterfowl or other model species—species that might differ substantially in susceptibility to toxic effects of oil from the wild species that are at risk. However, there appears to have been a lack of followup in efforts that might be most useful. Although excellent techniques for the detection and identification of hydrocarbon compounds in tissues were developed, we know of no continuing, regular monitoring for contamination of bird tissues in any OCS region currently producing oil or gas or in areas near major transportation corridors.

Several attempts were made to delineate "risky" areas on the basis of observed seabird distributions and on the basis of measures of patchiness. They included useful innovations in risk characterization, but the approach has not been followed up with applications throughout the several OCS regions. In particular, the risk modeling conducted for the Southern California Bight (Ford, 1985), although promising as a tool for identifying and measuring possible outcomes of a hypothetical oil spill, does not appear to have been followed up or generalized to other OCS regions. Thus, an opportunity to develop generalized risk models has not been exploited adequately. Likewise, there seems to be little attention to the effects of chronic contamination of low magnitude or of chronic disturbance.

Gaps in the Available Data

The panel sought to identify data deficiencies that were of central concern with respect to the goals of the ESP. The minimal program of studies that should have been included in the ESP from the start can be summarized as follows.

Colony Inventories

There are no known gaps in the inventory of seabird colonies. But almost none of the inventory counts provides a statistically adequate historical record against which to measure changes in population size. At too few colonies has there been the repetition of counts between years, let alone within years, needed for statistical soundness. Many surveys are now over 10 years old. The panel is aware that MMS is beginning to update colony censuses.

At-Sea Inventories

Large areas of the OCS have received little or no MMS coverage. We have almost no information on the birds at risk in those areas. The lack of coverage in the Gulf of Mexico is perhaps the most glaring deficiency; up-to-date survey data are also needed for Georges Bank. In some areas that have received coverage, the seasonal distribution of counts is uneven. The lack of surveys in Alaska during winter is of concern. Although such surveys are logistically difficult, winter is a time when birds might be concentrated in coastal areas or near the ice edge and thus be particularly vulnerable to spilled oil.

Coverage of most areas has been insufficient to detect major at-sea migration routes and staging areas. The passage of birds on migration is a transitory phenomenon during which major segments of the population of a species can be concentrated in small, traditionally used locations for brief periods. The locations and the timing of their use might be known to local residents, but are probably not known to MMS.

Shoreline Habitat Inventories

The inventories of the shoreline habitat and nearshore waters throughout most OCS regions are generally insufficient to let MMS assess the potential risk of impact or the actual loss of birds if an oil spill occurs; data gaps appear particularly severe for the coasts of the Gulf of Mexico, the middle and south Atlantic seaboard, Cape Cod, and the Gulf of Maine. Data are also apparently unavailable for the northern California, Oregon, and Washington coasts.

Colony Process Studies

Information on age-specific mortality, fecundity, and recruitment—critical for the construction of population models—is lacking. There are no data on dispersal, and there are no continuing long-term studies of reproductive ecology and its relationship to environmental change.

At-Sea Process Studies

With few exceptions, there is insufficient knowledge of the major foraging areas near large colonies and of the degree to which they are geographically fixed because of topographically driven marine processes. Information is lacking on the physical and biological processes that result in predictably greater availability of prey in particular locations.

More knowledge of the processes that determine the location of major concentrations of migrant and wintering birds is needed. At-sea processes responsible for concentrating birds have been best studied in the Bering Sea, central California, and Georges Bank, but are not well known for other regions.

Shoreline and Nearshore Process Studies

For many, if not most, of the known major staging areas, the energetic consequences and the resulting impact on bird populations of the partial or complete loss of what are thought to be critical habitats for both waterfowl and shorebirds are unknown.

Effects

There are insufficient data on the behavior of birds at oil slicks. Too few species have been studied, and the data on those studied are inadequate for predicting the proportion of birds likely to encounter oil in the event of a spill.

There is little or no information on factors that control the rates at which oil will be ingested and on whether oil is likely to be ingested primarily with food or through other activities, such as preening.

There is a lack of knowledge of the generality of the hemolytic and reproductive effects found by Fry (1987) in the full range of wild birds likely to be exposed to oil.

It is not now possible to assess the full number of birds killed in a spill with accuracy.

Data on the present prevalence of oil contamination on and in live birds in the wild are sparse. Spills that occur should be used as study opportunities to obtain these kinds of data.

Models and Estimation of Risk

The means are lacking to predict the number of birds at immediate risk because of any particular oil spill, other than one in the Southern California Bight, and even the risk-assessment model for the Southern California Bight lacks validation. It is not yet possible to relate episodic events, such as mass deaths in an oil spill, to population structure and consequent changes in populations.

Recommendations for Future Research

The panel identified the kinds of data needed if the goals of the ESP are to be met fully. Some of the required studies, however, are not feasible, given the length of time needed for their completion, the cost in relation to the information they could yield, or logistic problems that almost certainly would preclude success. The panel therefore recommends below the studies that are most urgently needed for addressing the central goals of MMS, but tempers its recommendations with considerations of feasibility and cost-effectiveness.

Colony Inventories

There needs to be a single, integrated data base in which all information on location, species composition, and population size is recorded and from which data can be retrieved for planning and for immediate use in case of a spill or other accident. MMS should select a subset of vulnerable or potentially vulnerable colonies for the creation of a statistically based historical record and monitoring program in which surveys of representative colonies will be kept up to date.

At-Sea Inventories

The most critical need is to integrate, to the extent possible, existing data bases and to create a real-time retrieval of data on the at-sea distribution and abundance of birds at any OCS location in any season of the year.

MMS should conduct at-sea surveys of marine bird distribution and abundance in regions with oil exploration or continuing oil development that lack adequate, up-to-date pelagic inventories and in other regions that lack pelagic inventories. It should also conduct focused studies of migratory routes to identify areas and timing of concentrations of birds, e.g., in the Straits of Florida, Bering Strait, and Aleutian Passes (a Unimak Pass study is in progress). Some at-sea distribution and survey data can be collected on platforms of opportunity, while some work might require dedicated research vessels. MMS should work cooperatively with NMFS, FWS, and relevant state agencies to plan cooperatively and carry out multi-disciplinary studies in regions of mutual interest and concern.

Shoreline Habitat Inventories

There is a need for a systematic inventory of shoreline regions used by birds near shore facilities or where oil-spill trajectory models suggest that oil might come ashore. Surveys of areas of such potential impact need to include not only avian use of salt marsh, lagoon, and intertidal flats and beach, but also nearshore waters to 5 km offshore.

Colony Process Studies

The panel recognizes that data on age-specific fecundity, recruitment, and mortality are important, but it is not practical to begin a project intended to measure them at this late stage in the ESP program. For most important species in Alaska, that would require a huge effort for at least 5 years to study recruitment, and 10-20 years to study age-specific mortality and fecundity. However, in a few cases, species might be relatively easily studied (e.g., eider ducks on the North Slope and pigeon guillemots in the Gulf of Alaska). In other cases, existing long-term studies of marked populations of known-age birds could be used for the construction of life tables (Nisbet, 1989). The life tables would be valuable for predicting the impact of oil-related activities on populations of the studied species and, by extension, other species.

MMS should give high priority to seeking cooperative agreements to construct life tables with investigators who have extensive populations of known-age marked birds. Species and locations that would be appropriate include black guillemots on the North Slope, various species on the Farallon Islands, various terns on the East Coast of the United States, brown pelicans in California, and possibly the Leach's storm petrel in the Gulf of Maine. MMS should seek cooperative agreements with the Canadian Wildlife Service, which has continuing, long-term studies of seabirds. Clearly, all available data sets should be used in designing a comprehensive program for studying bird colony processes.

At selected colonies of selected species, MMS should conduct annual studies of selected reproductive characteristics, including phenology, clutch size, chick growth, production of young, and food used. The monitoring studies should extend until the end of OCS activities in the area. At least one representative colony in each oceanographic domain with at least one species of each foraging type, to the extent practical, should be investigated. If suitable colonies are available for study, the panel suggests a minimum of one colony in the Chukchi Sea, two in the Bering Sea, and two in Prince William Sound, one in the Gulf of Alaska, one in northern California, one in southern California, and one in the Gulf of Mexico. The panel sees the resulting data as more important for monitoring the status of populations than mere counting of birds at colonies.

At-Sea Process Studies

MMS should conduct studies of the processes that affect the at-sea distribution of foraging birds near major colonies that are potentially exposed to oil spills from OCS activities. MMS should locate and study the spatial and temporal scales of processes responsible for the at-sea aggregation of seabirds, so that it can develop models capable of predicting the consequences of spills. The process studies should focus on areas where birds concentrate in active lease-sale and production areas. Information from other scientific disciplines must be integrated in the development of the new process studies; available at-sea marine bird data bases should be re-examined, so that it can be determined whether identified areas of concentration correspond with the location of known oceanographic processes or features. When possible, studies of oceanography, fish, resources, birds, and marine mammals should be planned and carried out cooperatively to develop comparative data sets and make the best possible use of available ship, aircraft, and other resources.

Shoreline Process Studies

For the major staging and wintering areas, MMS should measure the energetics of birds and model the potential impact of partial or total losses of staging areas on populations. For major staging and wintering areas, MMS should determine the relationships among density, number, residence time, and food availability and, if local food availability is found limiting, the behavioral mechanisms that regulate numbers of birds. Such information is needed particularly for waterfowl that winter inshore.

Effects and Risk Studies

MMS should improve its ability to use real oil spills, regardless of source, to study the behavior of birds on their first contact with spilled oil, and its physiological effects in the wild, as well as long-and short-term responses to oil spills and clean-up activities. This would require a contingency plan for real-time studies, preferably in cooperation with other responsible agencies. This point applies to marine mammals, fish, and other species groups, as well as birds.

There is a need for testing of more species of birds in the wild (e.g., shearwaters, alcids, and sea ducks) for sublethal toxic effects, such as reproductive failure and hemolytic anemia. For species shown to be vulnerable, factors controlling exposure should be investigated.

Studies of the movements of dead birds at oil spills should be conducted to help in determining what happens to bird carcasses. Further work is also needed to interpret the significance of the number of oiled birds on a beach relative to the population at risk or actually affected.

The presence of oil and oil residues in the tissues of selected species should be monitored at selected colonies.

Modeling Studies

MMS should develop and validate models designed to show how many birds are likely to be at risk in connection with any spill in an OCS area in any given season and the significance of the number of dead birds relative to the population that is at risk or is actually affected. The models should include both breeding and nonbreeding birds and should incorporate data on foraging distributions around colonies, as well as data on nonbreeding, or "passage" birds. Validation of the models with appropriate pelagic surveys (which could be combined with other survey programs) is essential.

On the basis of data acquired in process studies, life tables should be developed to relate adverse changes in survival or productivity to long-term population size and recovery rates; at the least, this will require extension and generalization of the model by Ford et al. (1982).

Criteria are needed for determining the smallest size effect regarded as "significant."

Coordination, Cooperation, and Organization

In discussions with MMS personnel, principal investigators, and people in various agencies, it became apparent that, at least within the marine bird studies, there has not been an overall ESP plan of work that has coordinated efforts among the various OCS regions, other federal and state agencies, and university-based investigators funded from other sources. Planning sessions involving knowledgeable people capable of setting priorities and making commitments have not been held regularly. Without such meetings at which priorities are decided and workplans are developed, coverage and effort become uneven and discontinuous. Without followup and development of processes for information transfer, data gathered in research not funded by MMS fails to be included in MMS data banks and reports. MMS needs more data than it can afford to acquire. The availability of mechanisms and inducements to investigators for sharing data (e.g., covering the cost of reformatting data tapes) could yield a wealth of information of value to the MMS planning and monitoring program. Likewise, data gathered by MMS could be of value to other federal and state agencies. The lack of formal mechanisms for sharing data and coordinating efforts is an aspect of the ESP that requires improvement.

SEA TURTLES

The Cetacean and Turtle Assessment Program, the MMS-funded study known as

CETAP (Winn, 1982), is discussed in the marine mammal section. It was conducted between 1978 and 1982 and covered the area from Cape Hatteras to the Canadian border, extending to just beyond the 1,000-fathom (1,830 m) isobath. The survey provided important data (now in need of updating) on the seasonal distributions of sea turtles in those waters and would have provided a reasonable basis for assessing the likelihood that turtles would come into contact with spilled oil.

The available information on the at-sea distribution of turtles farther south in the Atlantic Ocean and in the Gulf of Mexico is much less satisfactory. Fritts and Reynolds (1981) conducted a pilot aerial survey in the Gulf of Mexico, and it was followed by aerial surveys in the gulf and off the southern Atlantic coast in 1980-1981 (Fritts et al., 1983). Those surveys were too limited in scope and techniques to provide more than fragmentary information on turtle distribution. In 1989, MMS convened a workshop to plan future studies on sea turtles and marine mammals in the Gulf of Mexico. Workshop participants concluded that an information base needs to be developed to create models that would predict actual and potential human impacts, that distribution and abundance studies should examine habitats associated with different life history stages, in particular the pelagic habitat, and that priority should be given to the Kemp's ridley (Tucker and Associates, Inc., 1990).

Another NRC committee has recently reviewed the available data on sea turtles in U.S. waters, including information on causes of the recent decline in numbers of some species (NRC, 1990b). All five species that occur in U.S. waters are listed as endangered or threatened and are protected under the Endangered Species Act. Although much is known of their breeding distribution, of population trends, and of some aspects of their ecology (Bjorndal, 1981; NRC, 1990b), information on their at-sea distribution and vulnerability to oil is only fragmentary, especially for the Gulf of Mexico. Turtles appear to be attracted to oil platforms, especially east of the Mississippi River (Lohoefener et al., 1990), and there is evidence that the use of explosives in the removal of platforms kills turtles swimming nearby (Klima et al., 1988). The NRC committee (1990b) estimated, with considerable uncertainty, that oil-platform removal might cause 10-100 turtle deaths each year in U.S. waters "without protective intervention." Although it cited no other information on oil-related mortality of turtles, ingestion of oil and tar balls has been blamed for the deaths of young green turtles in Texas and Florida (Witham, 1981; Woody, 1986). The oil spill resulting from the *IXTOC I* blowout in 1979 probably affected Kemp's ridley turtles near their only known nesting beach in Mexico (Waldichuk, 1980), but the effects were not adequately investigated.

MMS's investigations of sea turtles, especially in the Gulf of Mexico, have been inadequate in view of the listing of the populations of these species in U.S. waters as endangered and their apparent vulnerability to OCS activities, although it has recently supported a study of the associations of turtles with oil platforms (Lohoefener et al., 1990). As pointed out in a recent NRC report (NRC, 1990b), available information on sea turtles in the Gulf of Mexico is inadequate as a basis for assessing potential effects. Lohoefener et al. (1990) also recommended additional studies of sea turtles in the Gulf of Mexico, especially east of the Mississippi River, to better assess the risk to them of platform removal.

Although little is known of sea turtle life history during the posthatching phase (NRC, 1990b), it is reasonable to expect that young loggerheads and Kemp's ridleys and perhaps other turtle species reside in the sargassum community, where currents converge in the Gulf Stream. Oil spilled during normal operations as well as oil from larger spills is likely to become concentrated in the convergences that also concentrate sargassum. Given the recent leasing and proposed OCS leasing for sites within the Gulf Stream, MMS should survey the sargassum community to determine the distribution and abundance of turtles there.

MARINE MAMMALS

Introduction

This section discusses the adequacy of the Environmental Studies Program for marine mammals-whether, in combination with data available from other sources, the ESP has provided a basis for an informed decision about the potential impacts of OCS petroleum operations. Marine mammals are especially important, because many are endangered species (e.g., many large whales, sea otters, and manatees); some have cultural, subsistence, and economic importance to Native American groups; many are highly valued by the public (e.g., dolphins, whales, polar bears, and baby seals); and all are protected by the Marine Mammal Protection Act. They can also be extremely difficult to study-all are highly mobile, none is a good "laboratory" species, and all are relatively long-lived. Previously, there had been few large-scale synoptic surveys in U.S. waters, so there was little foundation of information on which to build. Acquiring the data necessary to permit reasonable environmental assessments has presented a major challenge to MMS.

MMS has a general responsibility to understand what marine mammals are present within areas that are leased for exploration, their ecological relationships, and the potential impact of offshore petroleum operations on them. These studies should focus on the most sensitive and vulnerable species, life history stages, and processes. MMS should not however, as a rule, assume responsibility for collecting the data necessary for an understanding of the population dynamics of marine-mammal populations in all U.S. waters or conduct research on populations that have been adequately studied by other organizations.

We have subdivided our analysis into three parts: inventory, effects, and ecological processes. The first part deals with whether the spatial and temporal sampling of mammal populations has resulted in an acceptable description of the stocks, including seasonal patterns of distribution, movement, and abundance. The second part is related to the understanding of the effects of contact with hydrocarbons or other pollutants and of responses to noise and disturbance. The third is related to population dynamics and the ecological relationships that affect the distribution, abundance, and population trends of marine mammals.

Environmental Studies Program and Results

Inventory

Inventories of the species of marine mammals present and the seasonal patterns of their distribution and abundance are of fundamental importance in evaluating potential impacts. Because many marine mammals are migratory and inhabit remote locations, MMS has funded major aerial survey programs over the last decade. In fact, MMS has been the largest source of funding for studies of cetacean distribution and abundance in the United States. Its programs have been carried out in all the major frontier OCS areas.

At the outset of the Environmental Studies Program, little was known about the distribution, movement patterns, and relative abundance of cetaceans in OCS waters. The migration corridors and areas used seasonally were virtually unknown for most species. For preparing accurate EISs, it was important that information be obtained on whale presence in OCS waters. Consequently, major survey programs have been conducted in nearly all OCS areas, although not all were funded by MMS.

Studies of pinniped and sea otter distribution and abundance have often been combined with surveys of cetaceans and less commonly with surveys of seabirds. Almost all the surveys of pinnipeds have been conducted off the West Coast or in Alaskan waters. Estimates of abundance of pinnipeds, particularly of harbor seals and gray seals, along the East Coast have not been funded by MMS, but have been funded by other federal agencies, such as the Marine Mammal Commission, or private research foundations (Prescott and Gilbert, 1979; Payne and Selzer, 1987). The effort in the Pacific region has been focused on the California coast, although a study of the OCS off Washington and Oregon is now under way. Studies in the Alaska region have been conducted in the Gulf of Alaska, the Aleutian Islands, and the Bering, Chukchi, and Beaufort seas. The MMS-funded surveys have been complemented by a report on the status of 10 marine mammals in Alaskan waters (Lentfer, 1988) funded by the Marine Mammal Commission. All those accounts, each with special research and management recommendations, constitute a valuable compendium of recent information on distribution, population dynamics and trends, and conservation issues and needs. Most consider possible consequences of oil and gas development.

The MMS-funded surveys have been largely successful, but expensive. They resulted in descriptions of seasonal patterns of use, particularly by cetaceans, that have in some instances led to additional research on the role of these mammals in marine ecosystems. For example, MMS contracted with the University of Rhode Island to conduct a major survey program of the mid-Atlantic and North Atlantic areas from 1978 to 1982 (Winn, 1982); the study is popularly known as CETAP, the Cetacean and Turtle Assessment Program. The study area extended from Cape Hatteras, North Carolina, to the border with Canada and seaward to just beyond the 1,000-fathom (1,830 m) isobath. Data were collected through aerial survey, from observers placed aboard "ships-of-opportunity" and "aircraft-of-opportunity," and from chance observers.

CETAP resulted in a much-improved picture of the distribution of whales and dolphins in the mid-Atlantic and North Atlantic regions, and this has led to more detailed work, some of which is associated with the whale-watching industry that has recently developed there. The Great South Channel has been identified as an area of particularly high use by right and humpback whales. Similarly, the feeding concentrations of blue and humpback whales that were discovered through MMS surveys in the waters off northern California have become the subjects of detailed studies (Calambokidis, et al. 1990a,b). CETAP data were less reliable for small cetaceans than for large ones and no additional surveys were supported by MMS. Surveys directed at small cetaceans that replicate the CETAP study design are being conducted by NMFS (Gerald Scott, NMFS, SE Fisheries Center, Miami, Fla., pers. commun., 1991). The study will also include sampling in the South Atlantic and Gulf of Mexico.

Surveys of marine mammals in the Atlantic south of Cape Hatteras and in the Gulf of Mexico have been much less complete than those conducted elsewhere in the U.S. OCS. The Fish and Wildlife Service, on behalf of MMS, prepared a report on the marine mammals from Cape Hatteras south to the Florida Keys (Fritts et al., 1983). The report was based on aerial surveys in an area of 111 x 222 km off the central east coast of Florida during 1979, 1980, and 1981 and on other information. FWS also conducted surveys in the Gulf of Mexico in three rectangular areas; surveys were conducted every 2 months in the last year of the program. The areas measured 222 x 111 km, with the long axis perpendicular to the coast. One area was off the coast of Texas, near Brownsville; the second off the Louisiana coast, near Marsh Island; and the third off the west coast of Florida, near Naples (Fritts et al., 1983). Those surveys made up the first systematic offshore study of cetaceans in the Gulf of Mexico, but because the effort was far less than that in other studied areas, we do not believe that the information on cetaceans in the Gulf of Mexico is adequate. However, MMS has recently undertaken more extensive cetacean surveys in the Gulf of Mexico. Quantitative information is also needed on the use of the South Atlantic by right whales for calving purposes. An aerial survey of bottlenose dolphins was conducted by NMFS from 1983 to 1986 (Gerald Scott, NMFS, SE Fisheries Center, Miami, Fla., pers. commun., 1991).

For the region off the California coast, surveys of marine mammals and seabirds were combined (Dohl et al., 1981, 1983). Generally, they were intended to obtain an indication of the species present at different times of the year, and they were carried out with aircraft that flew transects along the California coast and with various survey designs. Bonnell et al. (1981, 1983) surveyed the California coast for distribution and abundance of marine mammals and seabirds; one study (1983) concentrated primarily on pinnipeds and sea otters along the central and northern California coast. Their transects were perpendicular to the coast to a distance of about 250 km. Line-transect analysis was used to estimate densities of the species involved, and attempts were made to consider shifts in yearly and seasonal distributions in the 3 years surveyed. There have been no comparable studies off the coasts of Oregon and Washington, although some are being conducted.

MMS expended its largest effort in the Alaska OCS region. Although cetaceans are abundant in Alaskan waters, relatively little was known about them before the MMS-sponsored studies. The Alaska region presents special problems for conducting surveys to determine seasonal distribution and abundance: much of the area is remote from bases of operation, weather conditions often are poor, and the winter day is short. Consequently, work in the Alaska region is very expensive and often difficult. Many of these surveys were done for operational purposes to meet the requirements of lease stipulations that seismic and other activities not be conducted when bowhead whales are present in the area.

The bowhead whale, which occurs in the northern Bering, Chukchi and Beaufort seas, presented a special problem to MMS. It is a high-profile species in two ways. First, it is legally classified as an endangered species; when preparations were being made for the first Beaufort Sea lease sale, it was commonly believed that the population might have numbered less than 1,000. (The most recent point estimate of population size accepted by the Scientific Committee of the International Whaling Commission in 1991 is 7,500 (IWC, 1991).) Second, it is the subject of an important subsistence hunt by Alaskan Eskimos. Consequently, a large proportion of the cetacean inventory effort has been focused on the movement patterns of this species. Surveys were done to obtain data on timing and median depth of fall migrations, and variations relative to ice conditions (Ljungblad et al., 1988; Traecy, 1988).

Generally speaking, the ESP has not funded studies whose primary focus is the development of new techniques of study; this is seen as lying outside the MMS mandate. However, because of both the limitations and the high cost of aerial survey for gaining information about whales, MMS has made an exception to the general rule: it has aimed research at developing a means of tagging whales with a device that would be linked to satellite receivers. This effort has not yet proved completely successful Methods for tracking large cetaceans were assessed in an MMS workshop (Montgomery, 1987). Such a satellite-linked radio tag would permit individual whales to be followed continuously, regardless of weather or day length, for extended periods and without using aircraft and human observers. Contracts were let to both the Woods Hole Oceanographic Institution (WHOI) (Watkins, 1981) and Oregon State University (Mate and Harvey, 1981, 1982) for the development of tags and systems to allow their attachment to whales. Although the species of greatest interest was the bowhead, development and testing involved more abundant and more accessible species, such as gray, humpback, right, and fin whales. The benefits of a satellite tag are great for understanding habitat-use and movement patterns. A fully operational tag has the potential to yield very important data on such subjects as critical habitat and the influence of offshore operations on migration behavior. Studies were also undertaken to determine the effects of the attachment systems, all of which involved invasion of the skin, on the whales themselves. Work undertaken at WHOI included an attempt to assess the effects of implanted radios on the skin of fin whales that were to be taken in the Icelandic commercial whale fishery (as governed by regulations and quotas determined by the International Whaling Commission). Laboratory work was undertaken at the University of Guelph.

Surveys of the distribution and abundance of seals and sea otters in lease-sale areas have been funded by MMS in most regions of the Pacific coast, including Alaska, although some of these surveys are over 10 years old. Combined with data gathered by other agencies, and within reasonable limits, these surveys provide adequate stock assessments for some species (harbor seals, sea lions, fur seals, and sea otters). There is somewhat more recent information for ringed seals. More information is needed on at-sea distribution, movement patterns, feeding habits, and feeding areas for all species to monitor changes in population size. Several of these species have been undergoing dramatic population declines. The basic understanding has been summarized in a readily accessible publication (Lentfer, 1988).

A comprehensive polar-bear research program has been under way in the Fish and Wildlife Service since the 1970s, and so there was no need for MMS to duplicate such a program. MMS has, however, provided FWS with supplemental funding and logistics support (Cleve Cowles, Chief, Environmental Studies Unit, Alaska Regional Office, MMS, pers. commun., 1991). FWS has studied population size, movements, denning location and behavior, and production and survivorship of cubs (Amstrup et al., 1986). That information is adequate for impact assessment at the lease-sale stage.

FWS has also had an extensive program of research on manatees and has adopted a manatee recovery plan because of their status as an endangered species (FWS, 1989). Although manatees reside primarily in fresh water on coastal waterways in Florida, they come into salt water to forage on sea grass and to move seasonally from one coastal area to another. It is important for MMS to document use of marine habitat and foraging areas where oil could come ashore and where there is potential for collisions with boats and barges.

Surveys of marine mammal abundance are now being done in the entire outer continental shelf by NMFS as required by the MMPA for purposes of managing bycatch of marine mammals by fisheries. While these surveys will be useful to MMS, they do not address seasonal or overall distribution.

Effects

The relatively large size of most marine mammals and their protected status would make them poor experimental subjects, even if they became available for study. The primary concerns are related to the effects of spilled oil and to disturbance by underwater and airborne sound. Most of the research has been short-term research.

Direct Observation of Marine Mammals in the Presence of Oil

It has been possible to study cetaceans in the wild to observe their responses to oil slicks from spills and from natural seeps. During the CETAP project, Goodale (1981) observed both dolphins and baleen whales behaving apparently normally in slicks of crude oil that resulted from the sinking of the tanker *Regal Sword* off Cape Cod; some humpback and fin whales seemed to be feeding in the slick. As part of MMS-sponsored research, Evans (1982) observed gray whales swimming through oil slicks from natural seeps off the California coast. Other researchers, not funded by MMS, have also observed dolphins in the presence of oil (Sorensen et al., 1984; Gruber, 1981). These observations indicate that cetaceans do not appear to avoid oil.

Very little work has been done on how pinnipeds and sea otters might respond behaviorally to the presence of oil. Sea otters are particularly vulnerable, because oil contamination soils their fur, destroying its insulating properties. Consequently, oiled sea otters often die from hypothermia or the toxic effects of oil that is ingested as they groom themselves. Even though the oil that is transported through Prince William Sound does not come from an OCS source, and MMS was not the primary agency responding to the *Exxon Valdez* spill, MMS responded quickly to provide some funding for studies that could take advantage of the opportunity it presented. Research efforts on sea otters were, however, managed by FWS, the agency responsible for sea otter management. Results of those studies will become available as legal restrictions permit.

Physiological Studies of Contact with Oil

Contact with oil might damage the skin, plug the nares, clog baleen, or possibly cause some other mechanical interference with affected animals' activities. For both legal and logistic reasons, it is impractical to expose whales to an experimental oil spill or to feed them oil experimentally. Geraci and St. Aubin (1980) examined the effects of oil on the flow of water through baleen taken from fin, gray, humpback, and sei whales, and Braithwaite (1983) investigated the effects on bowhead whale baleen. They found that the heaviest treatments of oil could impair filtering efficiency for a period of hours to a few days, but that the effects were reversible.

Geraci and St. Aubin (1982, 1985) found no apparent inflammation after exposure of small areas of skin of captive dolphins to crude oil and only slight inflammation after exposure to unleaded gasoline; reaction of the skin of human volunteers exposed to the same gasoline was greater. They also found no allergic contact dermatitis after repeated exposure to aromatic hydrocarbons; they reported little to moderate cellular damage after such exposure, but it was reversible. Although the most severe exposures (75 min of continuous contact) produced definite effects on dolphin skin, the effects were reversible and appeared to be no more severe than effects on the skin of other mammals. The most severe exposures exceeded those reasonably expected to result from a spill involving free-ranging animals that would be at the water's surface for only brief periods. The study concluded that the potential for severe effects of contact of cetacean skin with petroleum is much less than was commonly suspected earlier and that adverse effects may be temporary on species that do not rely on fur for insulation.

The ESP has funded work on the effects of oil on fur seals and sea otters. Both species rely on their thick fur to insulate them. When the fur becomes soiled with oil, it loses its insulating function, and many of the animals die of hypothermia. Costa and Kooyman (1981, 1982), Tetra Tech (1986), and Davis (1986) investigated the effects of oil on sea otters and their habitat and sought ways to rehabilitate such animals and return them to their environment. Their studies have generally shown that sea otters are extremely vulnerable to oil contamination, but that cleanup of individual animals is possible, if facilities and trained personnel are available. The ability of cleaned and rehabilitated otters to survive in the wild is uncertain.

Studies in Canada by Geraci and Smith (1976) suggested that the thermoregulatory effect of oil on ringed seals was not as great as on animals that depend on their coats for insulation. Those results would probably be the same in other seals that do not use their fur as major protection against hypothermia and in sea otters with respect to damage to internal organs. Similar studies done with captive seals resulted in death of the animals, possibly because of the added stress of captivity (Smith and Geraci, 1975), indicating that the effect of spills may depend in part on other variables, such as the time of year, that affect the general condition of the animals at the time of the spill.

Geraci and St. Aubin (1982) reviewed the literature on ingestion of petroleum by other mammals and concluded that it is unlikely that any cetacean would ingest enough spilled oil to cause its death. Because the light fractions of petroleum would rapidly evaporate and would be carried away from the area of an oil spill, they concluded that exposure to petroleum vapors was not a likely potential cause of harm to cetaceans from an oil spill.

As the following quotation from Geraci and St. Aubin (1987) suggests, there has been little experimental study of the relative toxicity of ingested oils on marine mammals:

> There have been three oil ingestion experiments in seals and one in cetaceans. Harp seals given a single dose of up to 75 ml (1-3 ml/kg) of crude oil began to excrete oil in the feces within 1.5 h, suggesting increased gastrointestinal motility (Geraci and Smith, 1976). Some was undoubtedly absorbed into blood and tissues, as was shown in studies of ringed seals given smaller doses (0.2 ml/kg/day for 5 days) of oil (Engelhardt et al., 1977; Engelhardt, 1981). There was no gross, microscopic, or biochemical evidence of tissue damage in either species. A bottlenose dolphin given small quantities (2.5-5 ml) of machine oil daily for over three months also showed no clinical signs of organ damage or intoxication (Caldwell and Caldwell, 1982).

The discovery after the *Exxon Valdez* oil spill that several killer whales were missing from pods in Prince William Sound raises questions about the effects of oil on cetaceans (Trustee Council for the *Exxon Valdez* Natural Resource Damage Assessment, 1991) and suggests the need for tissue sampling following oil spills. At the time of writing, the recent data on Prince William Sound killer whales are being kept confidential, pending possible litigation. When these data become available, it will be possible to better evaluate and clarify the potential explanations.

The only research conducted on oil effects on polar bears was an experiment involving three bears in Canada near Churchill, Manitoba (Engelhardt, 1981; Oritsland et al., 1981; Hurst and Oritsland, 1982). The bears were forced into an oil-covered pool and suffered hypothermia and various toxic effects. Two of the bears died as a result of toxic effects of oil, and the other survived only after an intensive and prolonged period of treatment. There has also been one documented case of a polar bear dying after consuming ethylene glycol (antifreeze) (Amstrup et al., 1989). There does not appear to be a need for MMS to fund additional research on effects of oil on polar bears.

MMS has sponsored research on the effects of oil on sea otters. It included behavior of captive animals exposed to slicks (Siniff et al., 1982), thermoregulatory effects (e.g., Costa and Kooyman, 1981, 1982), and cleaning and rehabilitation of the otters (Davis et al., 1988; Williams et al., 1988). Others have studied oil and otters, both experimentally and opportunistically. The value of rehabilitating otters and releasing them to the wild is controversial, because the process of rehabilitation is expensive, the number of animals that can be treated is small, and the survivorship of animals that are rehabilitated and released appears poor (Monnett et al., 1990).

Almost nothing is known about the effects of oil contamination on manatees. It is possible that oil ingested with food could affect the microflora in the animals' digestive tract essential for digesting cellulose. Barge and boat traffic is extensive in the inland and coastal waterways of Florida where manatees live, so the animals are chronically exposed to low concentrations of petroleum. However, there are no studies of effects.

Geraci and St. Aubin (1990) and Richardson et al. (1989) have summarized the results of research sponsored by MMS and others on the effects of oil on marine mammals.

Sources and Characteristics of Underwater Sound

Over the last few decades it has come to be recognized that marine mammals live in an environment greatly affected by sound. Sound travels much farther in water than light does and it can be detected in the dark. Marine mammals make great use of underwater sound for various purposes and at various frequencies. Baleen whales use sound for communication and probably for obtaining information from their environment; toothed whales use sound for echolocation as well. Because offshore petroleum operations involve activities that produce underwater sound, there is a potential for them to interfere with sound produced by cetaceans as well as to cause disturbance and stress. Even as recently as 1980, there was very little information about the frequency composition and intensity of underwater sound produced by such petroleum-related activities as drilling, dredging, and vessel traffic or the intense sound produced during seismic exploration. And there was almost no information about the efficiency of sound transmission through water. MMS has invested considerable effort in research on the characteristics and effects of underwater sound.

Gales (1982) studied the underwater sound from oil-production platforms in Santa Barbara Channel, California, and in Cook Inlet, Alaska. Greene (1987) studied the sounds produced by dredges, drilling operations, and vessel traffic in the Canadian Beaufort Sea. The sounds produced by those operations tended to be of low frequency; the majority was below 500 Hz. Helicopters and, to a much smaller extent, fixed-wing aircraft are also used in offshore petroleum operations; they also tend to produce sound mostly below 500 Hz. The energy impulses used for seismic profiling are produced by nonexplosive means, such as with air guns that release pulses of compressed air. Greene (1982) found, for example, peak sound pressures of 242-252 dB 1 meter from the source. Seismic sounds are by far the most intense sounds produced by the petroleum industry; under some conditions, they can be detected up to 100 km away.

The transmission of sound underwater is complex and depends on a number of factors, including water temperature, salinity, depth, the presence of ice, ambient noise, and the nature of the sea bottom. Because of the complexity, simple general equations are unreliable predictors of sound propagation, and so empirical observations in each location of interest are necessary. Greene (1987) and Miles et al. (1987) have derived empirical equations for the attenuation of sound with distance at particular locations in the Canadian and Alaskan Beaufort Sea. The distance over which sounds are detectable depends not only on the intensity and the rate of transmission loss, but also on ambient (background) noise and hearing ability. Ambient noise arises primarily from wind and storms, ice movement, biological sources, and shipping activity. Some effort has been expended in measuring the natural ambient sound in the Beaufort Sea (Greene, 1987; Miles et al., 1987).

Assessing the potential effects of industrial noise on whales depends not only on the nature of industrial sounds, but also on the nature of the sounds made by the whales themselves. Consequently, a large number of recordings of bowhead sounds have been made by Greene

(1987), Wursig et al. (1985), and Ljungblad et al. (1987). Their calls typically can be described as moans, groans, growls, and trumpetlike sounds. The frequencies of most bowhead sounds are below 1,000 Hz, although some are up to 2,000 Hz. Data on various factors related to noise produced by OCS activity, sound transmission in water, ambient sounds and sounds made by the whales themselves, and disturbance responses can be combined to define a "zone of influence" in which marine mammals can be affected by noise. Although these zones cannot be precisely estimated because of limitations in available data and the necessity of relying on assumptions, the attempt to do so is a useful way to discover data gaps (Richardson et al., 1989; Davis et al., 1990).

Effects of Underwater Noise and Disturbance

Sound sources in the water can be characterized as moving (i.e., vessels), stationary (i.e., dredging and drilling operations), aircraft, and seismic. MMS played an important role in funding research on the effects of underwater sound on cetaceans. Many of the points covered were identified in an Acoustical Society of America workshop held in 1981 (ASA, 1981). Information on the response of whales to underwater sound and disturbance is derived from two basic types of situations. First, it has been possible on many occasions to observe bowhead whales close to various industry operations; but opportunistic observations lack controls for comparison. Second, experimental observations have been possible under more controlled circumstances; these have sometimes involved playback of recorded sounds and sometimes full-scale operations that have been under control of scientists conducting the work. MMS studies have focused on baleen whales, in particular bowheads (e.g., Richardson, 1985; Richardson et al., 1991) and to a lesser extent gray whales (Malme et al., 1983). A species of toothed whale, the white whale, has also been the subject of one study (Stewart et al., 1983).

Bowhead whales were the primary species of concern in the Alaskan Beaufort Sea, an area that was considered particularly likely to yield oil and gas, owing to its proximity to the supergiant Prudhoe Bay oilfield. As an early step to understanding the problem that might be presented by underwater sound, the U.S. Naval Ocean Systems Center (NOSC) recorded sounds produced by production platforms of various sorts in several areas and collected observations of whales made by persons working on the platforms (Gales, 1982). The NOSC analysis included sound intensity and frequency. LGL Limited (Richardson, 1985) began a study in 1980 of bowhead whales in the Canadian Beaufort Sea, the summer feeding grounds, where offshore exploration had been under way (outside the Mackenzie River estuary) since 1976. The largest and most extensive study of the response of whales to disturbance was conducted from 1980 to 1984 in the Canadian Beaufort Sea (Richardson, 1985) with additional work in the Alaskan Beaufort Sea (Ljungblad et al., 1987). The clearest response of bowhead whales to an industry activity was the response to vessel traffic. Obvious responses usually began when a vessel approached within 1-4 km of the whales. MMS also funded studies that defined zones of influence of activities on cetaceans (Richardson et al., 1989, 1991; Davis et al., 1990).

Beginning in 1978, NOSC began studies of bowheads in Alaskan waters, primarily the Beaufort Sea. The main aim was to study the timing and location of bowhead movements in spring (April, May, and early June) and fall (late August, September, and October). In some years, responses to seismic exploration were also studied. These studies were intended to be used for determining whether the bowheads' migration corridor was displaced offshore by industry activity. However, it is not clear that the data have been appropriately analyzed in this context.

The communication of baleen whales is probably more susceptible to interference from

OCS activity than that of other whales because the dominant frequencies in their calls overlap with the dominant frequencies of industrial sounds (Davis et al., 1990). However, the importance of such effects cannot be determined until there are data on the hearing ability of baleen whales.

In general, ship traffic and aircraft overflights can cause short-term behavioral reactions and temporary local displacement of some marine mammals. Elevated noise levels might mask natural sounds that marine mammals rely on, and there might be a long-term reduction in utilization of heavily disturbed areas by some species (Davis et al., 1990).

Ecological Processes

Population Ecology

The research necessary to estimate and monitor the vital characteristics of the population ecology of marine mammals within a geographical area with sufficient precision to be useful requires a long-term commitment of funds. For high-profile species, especially those which are particularly vulnerable, data of this nature are required, if population modeling and analysis have a high priority. North Pacific fur seals and California sea otters are examples. Where possible and appropriate, MMS should focus on species, populations, life history parameters, and locations that could serve as indicators, i.e., be of most use for extrapolation with careful validation.

We believe that studies of the population ecology of marine mammals in areas that might be affected by development are appropriate. However, we caution against overreliance on such studies as a basis for monitoring effects, although they could provide information that is essential for assessing potential impacts and population-recovery times. The dynamics of marine-mammal populations are affected by many factors; even if the populations could be monitored precisely enough to detect important changes, it might be very difficult to know whether the underlying causes are related to petroleum development. We recommend that population monitoring studies include an attempt to identify causal linkages, to ensure that clearest indicators of effect are studied.

Modeling of Interactions Between Oil Spills and Marine Mammals

The environmental studies program has recently funded modeling efforts that have attempted to explore the effects of oil spills and other petroleum-related activities on various marine-mammal populations. Reed et al. (1986) summarized existing data on northern fur seals into a model for studying the potential effects of oil spills in the Bering Sea on the population dynamics of this species. Their study used data on migration routes and other population characteristics to explore what would happen if oil contamination existed in particular areas of the Bering Sea at different seasons. The study was useful in pointing to the need for additional data if such modeling efforts are to be more predictive. Siniff and Ralls (1988) performed a 2-year field study on California sea otters and obtained population and movement data. Their data were added to existing data to construct a population model to help in predicting the effect of oil spills along the California coast. That study, too, was valuable in helping to predict times for the population to recover from oil spills of different sizes and in different regions of the California coast. It also pointed to the need for additional information to support predictive modeling: data on population characteristics, such as survival of sex and age classes, changes in reproductive rates from one year to the next, and the variance of various population measures.

Applied Science Associates undertook a computerized simulation study aimed at integrating information on the location and timing of the migration of bowhead and gray whales with oil-spill trajectory models to arrive at the probability of interaction between oil spills and these species (Reed et al., 1987). The usefulness of models of this sort is limited by their inability to incorporate microscale behavior of oil and the response of whales to oil. Thus, the models might provide a reasonable picture of the potential for whales to be in the proximity of oil, but not of the degree to which there will be contact.

Trophic Studies

Trophic studies have been done in both the Alaskan and Canadian Beaufort seas to determine if changes in abundance of bowhead whales are correlated with changes in oceanographic conditions, and productivity. Griffiths and Buchanan (1982) found that changes in distribution of bowhead whales were related to oceanographic conditions. Richardson (1987) found that the changes were related to food availability caused by the presence or absence of upwelling. Thomson (1984) examined feeding patterns of gray whales in the Bering Strait area. A study of pinnipeds in the Bering and Chukchi seas analyzed stomach contents of seals to understand how the animals function ecologically (Lowry et al., 1981a,b). A current study, the South Channel Ocean Productivity Experiment (SCOPEX), cofunded by MMS and NSF, is examining the relationships among right whales, zooplankton, and the physical and biological environment. The study is based on oceanographic sampling, whale tagging, and aerial surveys conducted in the Great South Channel where humpback whales congregate at particular times of year.

Studies of trophic relations and food availability, conducted over a period of several years, should help provide understanding of spatial and temporal variability in the distributions of marine mammals.

Gaps in Available Data

Inventory

The results of MMS studies have formed a general picture of seasonal and geographic variation and of the use of particular areas by cetaceans in most OCS waters. Exceptions are the South Atlantic, the Gulf of Mexico, and off Washington and Oregon, although surveys are under way in the latter two areas. The information base could be improved with considerable effort as has been expended for the bowhead whale, although we question whether the need for the large bowhead effort has been justified scientifically. These studies were driven primarily by legal and political pressures that have been present because of the requirements of the ESA and MMPA, and the importance of bowhead whales as a subsistence resource for Alaskan natives.

More detailed and intensive study of whales is justified in specific areas proposed for development after exploration has determined that commercial quantities of petroleum are present. Such research should aim to determine the numbers of animals using an area, movement patterns, and the ecological function of the area (e.g., feeding, migration, etc.). In studies that focus on a relatively circumscribed area, research might include vessel-based observation incorporating identification of individual animals, as well as aerial surveys. The use of satellite tags is potentially valuable here (Mate, 1989, 1991).

Information on pinniped and sea otter distribution and abundance in several OCS areas is lacking. Particularly lacking on the U.S. east coast are MMS-funded projects that consider distribution and abundance of harbor seals and gray seals; as mentioned earlier, some information has been collected by other government agencies or through private funding, but additional MMS effort is needed to provide a historical record of changes in their population. Available information (Gilbert et al., 1979) suggests that gray seals are increasing in some regions of the northeastern coast. The role of gray seals in the ecosystem is virtually unknown, and monitoring the increase in their abundance would be valuable for correlation with future changes in ecosystem structure and function. Otherwise, if changes in abundance accompany oil and gas development, it will be difficult to separate the influence of development from unrelated causes of change. If extensive exploration or development is planned near seal habitat, MMS should undertake studies of seals.

Surveys have been done along the Pacific coast in California; in some locations along the Alaska Peninsula, particularly in the Cold Bay-False Pass region; and in some locations of the Bering Sea and are going on in Oregon and Washington. Ice seals have been surveyed along the northern coast of Alaska. Those areas are important with respect to oil and gas leasing programs.

Although there has been much oil-related development in Prince William Sound, little research has been done there; however, oil that is transported through Prince William Sound comes from onshore locations near Prudhoe Bay, and not from OCS areas that would fall within MMS's responsibility. Because of the pipeline terminus and the importance of the region with respect to transport of oil, some long-term studies of cetaceans, pinnipeds, and sea otters are appropriate. The Fish and Wildlife Service has conducted long-term sea otter studies in the region, so the general population status of this species is well known. However, data on cetaceans and pinnipeds of the Prince William Sound region are sparse, although some seasonal surveys have been made. Because this area seems to be at high risk, basic inventory and process studies on all marine mammals would also be appropriate. Although there is some question about which agencies should assume responsibility, MMS should continue to take part in these studies, as it did after the *Exxon Valdez* spill, because of the opportunities to examine actual effects of spills and because of the importance of the region for the transport of oil

The need for further information on distribution and abundance of pinnipeds and sea otters will depend in large part on future leasing plans and discoveries that could lead to development. Information on distribution and abundance is one of the first items necessary, in light of legal requirements with respect to leasing programs. Data on distribution and abundance in most locations are largely insufficient for documenting normal annual variations. Therefore, the effects of oil and gas development on a given region are impossible to document, because they might be well within the range of variation caused by other environmental factors. That suggests that monitoring studies should take into account mechanisms of potential impact. Distribution and abundance data have been collected over just a few seasons before leasing programs have begun. Lessons from prior studies point to the need for longer-term data in regions where oil and gas development is likely to occur but before development occurs.

Effects

The effects of oil and gas exploration and extraction have been considered in the

Environmental Studies Program. The effort has centered mostly on the noise generated in these processes. Kelly et al. (1986) considered the effect of noise disturbance from on-ice seismic exploration on ringed seals, as did an earlier study by Cummings et al. (1984). Those studies considered whether the noise produced by oil and gas exploration and extraction have important impacts. In general, the studies have shown that the noise impacts are localized and not likely to have large population consequences. Similar studies by Riedman (1983) considered the effects of marine seismic noise on sea otters in California and came to a similar conclusion. As mentioned previously, modeling efforts on the effects of OCS activities on marine mammals have been useful in pointing to the need for additional data as described below.

Considerable information has been obtained on the effects of oil contamination on the two most sensitive species: sea otters and fur seals. These studies have generally shown that rehabilitation of the two species after oiling is possible, but have pointed to the need for extensive facilities where rehabilitation programs can be executed.

It seems likely that the information obtained from the earlier Canadian studies on ringed seals can be transferred to other pinniped species that do not rely on fur for protection from hypothermia. A recent review by Geraci and St. Aubin (1990) is a valuable resource with respect to gaps in data on the various species of marine mammals. It seems that many data on effects can be transferred from one species to another for which insulation by fur is not a problem.

The California sea otter has been designated as threatened under the ESA because of its small population size and the increased risk of spills from tankers carrying oil. As described above, Siniff and Ralls (1988) pointed to the need for additional information on population characteristics such as survival of various sex and age classes, changes in reproduction rates from year to year, and a sense of the variance of the various population characteristics from one year to the next.

Ecological Processes

Little work has been done in process studies on pinnipeds. Information on trophic relationships of some of the northern species is available from collections from previous MMS studies (Lowry et al., 1981a,b). However, further information on ecosystem processes—knowledge of major foraging areas, seasonal variation in prey species, potential areas of competition between pinniped species for food, and general knowledge of various population characteristics—is virtually lacking for most pinniped species, on both the east and the west coasts of the United States. Information on feeding areas of the northern sea lion is becoming available through studies of its decline and its apparent interactions with fisheries of the high seas and coastal areas.

The information on walruses and sea otters with respect to trophic interaction and food-web relationships is much better. A recent monograph by Riedman and Estes (1990) reviews sea otter behavior, ecology, and natural history. Estes and Jameson (1983) have provided detailed information on the relationship between sea otter populations and the nearshore community. Data are still lacking that could tie changes in population characteristics—reproductive rates, survival rates, amount of time spent foraging, and sex-age interactions—with the structure and function of the nearshore community. Recently, Siniff and Ralls (1988) have provided some insight into the relationship between these characteristics and the animals' population status in California. However, data on sea otter populations at different locations in Alaska are lacking. The feedback mechanisms between prey abundance and walrus population are not well understood.

Conclusions and Recommendations

Inventory

MMS has funded comprehensive surveys of marine mammals, particularly cetaceans. The information that has been gathered on seasonal patterns of use of most U.S. waters by marine mammals has provided an understanding that is generally adequate for assessment of the potential for damage from OCS activities, but not as the basis for assessing change (including the measurement of impacts of actual events). Additional site-specific information will be needed for the latter purpose.

The surveys of bowhead whales in the Beaufort and Chukchi seas have been extensive and prolonged. Bowhead whales have received uniquely thorough study because, in addition to legal requirements, the entire Alaskan range of this species is scheduled for oil and gas leasing, because it is an endangered species, and because it is the object of a very important subsistence hunt by Alaskan Eskimos. In view of the present, much-improved understanding, MMS should re-examine the need for continuing the high level of attention that the bowhead receives; MMS should convene a workshop of experts on bowhead whales to examine the need for further bowhead research and to consider the possible value and design of site-specific and population monitoring.

There has been controversy over the median depth analysis (an analysis based on the median depth of water in which bowhead whales are observed) that has been standard for the bowhead fall-migration data. Reanalysis of the data based on different criteria seems appropriate. Reanalysis could be initiated through a small workshop in which biases in past analyses could be discussed and improved procedures identified, e.g., sensitivity analysis.

Information on seasonal distribution and abundance of marine mammals in the Gulf of Mexico and South Atlantic regions is incomplete at present. In those regions, additional surveys are needed, focusing particularly on patterns through the entire annual cycle. This is particularly important, because of the current degree of exploration, development, and production in parts of the regions.

Effects

The bulk of the existing information on the behavioral responses of cetaceans to noise and disturbance from offshore petroleum operations is derived from studies funded by MMS. In addition, to support the disturbance studies, much research was conducted on the nature and transmission of underwater sound produced by petroleum operations. Those studies have yielded a good understanding of the types of responses exhibited by cetaceans and the distances over which the responses occur.

One need is for an investigation of the behavioral phenomenon of habituation (i.e., the diminution of response of an animal after repeated exposure to harmless stimuli, such as noise from aircraft flights or nearby vessel traffic). Many wild animals commonly show a great deal of tolerance to human activity, e.g., birds nesting and feeding near active aircraft runways and busy highways. It would be useful to understand better how the ability to habituate might affect the long-term responses of marine mammals (and birds) to effects of OCS development. It is also possible that diminution of response is a product of physiological stress (e.g., adrenal depletion) rather than habituation, and this hypothesis needs to be tested. To determine the significance of individual noise sources in masking the sounds made by marine mammals, it would be useful to better understand the functions and significance of the sounds that marine mammals make. Data on the hearing ability of some species, particularly baleen whales, would also be useful, although perhaps difficult to obtain (Davis et al, 1990).

After an oil spill, much effort is expended on rehabilitation of oiled animals. That effort is extremely expensive. In the case of sea otters in Prince William Sound, probably only a small fraction of the animals contaminated with oil were captured and treated (Trustee Council for the *Exxon Valdez* Natural Resource Damage Assessment, 1991), and many of the animals captured died either in captivity or shortly after release. The rehabilitation effort had little effect on recovery of the Prince William Sound sea otter population. Rehabilitation operations exist for humane reasons, but are unlikely to increase population size or health in a manner that will increase recovery rates. That might not be true of small populations, and in instances where the animals affected represent a large proportion of an endangered population, but the population size at which rehabilitation is effective in enhancing recovery remains to be determined. Rehabilitation of marine mammals (and birds) needs to be examined in a population context. Considerable review of and planning for sea otter rehabilitation have been done by FWS and California as part of their effort to translocate southern sea otters to San Nicolas Island (FWS/California Department of Fish and Game, 1989). Workshops focusing on the matter are appropriate, particularly before MMS spends much money on rehabilitation centers and other facilities. Such a workshop might also examine this question in relation to marine birds.

The question that always arises after oil contamination has affected populations and ecosystems is the length of time needed for recovery. Recovery of ecosystems involving marine mammals is complicated, and rates of recovery are often difficult to predict, because of the lack of information on density-dependent responses and trophic relationships. Studies to gain information for assessing recovery in areas where oil or mineral development has occurred are appropriate. Such recovery depends on local circumstances. For example, are animals from surrounding areas available for colonization? Is the whole population, or some fraction, likely to be affected? Estimates of local survival rates, reproductive rates, and other population characteristics before any spill or other environmental event will be necessary, if recovery times are to be predicted. The exact nature of studies and data needed for such considerations are tied to local situations and the species of marine mammals involved.

Many OCS activities on the north coast of Alaska might take place in winter months and could have effects that are specific to polar bears. In the winter months, female polar bears producing cubs retire to dens, while others are active on the ice. Potential effects and specific research needs were identified in a January 1989 workshop sponsored by the Marine Mammal Commission. Research needs identified by the workshop include the identification of denning habitat and ways to reduce human interactions with polar bears (Lentfer, 1990). Those recommendations should be considered and evaluated in planning studies for polar bears.

MMS has sponsored a relatively complete suite of studies on the effects of oil on whales, sea otters, and fur seals and on rehabilitation of oiled sea otters; studies on the effects of oil on hair seals have been conducted by other researchers. Although some questions remain, legal and permit constraints and public opinion prevent additional experimental work.

MMS should be prepared to study the effects of oil on marine mammals when oil spills present the opportunity. We recommend that MMS enter into agreements with the appropriate agencies—i.e., FWS and NMFS and state agencies—regarding the necessary protocols and contracting procedures so that the research possibilities presented by "spills of opportunity" are not lost.

Ecological Processes

MMS's efforts on distribution and abundance have yielded information on the species and numbers of marine mammals that might be present at a particular location at some time, but not basic details of population dynamics or data on diet and habitat that would be necessary to determine indirect (e.g., food-chain) effects. The exception to that generalization has been related to sea otters in California. For key species, it is appropriate to collect basic data to document and understand causes of trends in populations and to predict recovery times in the event of a major impact. However, we recognize that the necessary effort will not be possible for all species or all areas. For example, long-term data on harbor seals and northern sea lions in the Prince William Sound area before the *Exxon Valdez* spill are minimal. Some survey data are available from MMS contracts with the Alaska Department of Fish and Game and other sources, but they are sparse. Data on characteristics such as reproductive rates, survival rates of young during lactation, and survival through the first year of life are all needed and would have been useful for comparison with estimates after the *Exxon Valdez* spill.

MMS should consider studies to obtain estimates of population measures in areas and for species most likely to be affected by OCS oil development and associated activities. The northern sea lion, the northern fur seal, and the harbor seal (in some areas) are declining in abundance and should be considered for such studies. Harbor seals are considered to be nonmigratory, so their populations could be affected substantially; studies of this species in areas where oil development has occurred or is likely to occur would be appropriate.

An understanding of the underlying factors that govern the distribution and ecological relationships of key species is important for assessing the potential for impact and for distinguishing natural changes from those anthropogenic changes. Process studies should collect information on food and feeding behavior and the factors that control food distribution. A general knowledge of processes is necessary at the leasing and exploration phase, but we do not believe that it is necessary for MMS to conduct detailed site-specific studies that are not related to general process questions until there is a discovery that could lead to development and production. There might, however, be cases where the concern or extent of activity is so great as to justify a more complete range of studies than would normally be considered appropriate, such as the cases of the bowhead whale and California sea otter.

Data Management and Accessibility

The data collected by MMS-funded researchers are of little use if they cannot be accessed. Data management can take several useful forms in addition to making final reports available: archiving original data, placing data in an interactive computer format, preparing papers for publication in refereed journals, and publishing books. MMS has increasingly recognized the importance of publishing the results of research, and has supported it, but there is room for improvement, particularly with respect to older work. Private contractors, in particular, need to be funded to permit them to publish and make data more widely accessible. Otherwise, financial pressures can make these activities difficult.

BENTHIC STUDIES

The Minerals Management Service and the Bureau of Land Management before it have spent over $128 million from 1974 to 1988 in the Environmental Studies Program for studies of the benthic environment. The studies have included analysis of the benthic fauna and physical and chemical characteristics of the habitats of interest for OCS development (See Tables 3-1 to3-5). Under authority of the Outer Continental Shelf Lands Act (Section 20), the ESP has the responsibility of providing an adequate description of each environment before leasing regions of the OCS for oil and gas exploration and development and of monitoring the environment during these activities to document environmental impacts. Studies of benthic organisms have been seen as key elements of both preleasing descriptions and monitoring, because these organisms are thought to be relatively susceptible to contaminants that settle to the seabed and because their relatively stable populations and sessile nature would make them suitable for impact assessment.

Accomplishments of the Environmental Studies Program

The panel assessed the benthic programs supported by the ESP and evaluated their contributions to advances in marine benthic ecology and predictions of the impacts of OCS operational activities. The effects of some OCS activities, such as the discharge of drilling fluids and accidental oil spills, and the long-term effects of offshore oil and gas development have been reviewed extensively by previous groups (NRC, 1983, 1985; Boesch and Rabalais, 1987). More recent studies (e.g., Neff et al., 1989; Chapman et al., 1991) have added to our knowledge, but they have not changed the overall picture. Therefore, the panel limited itself to reviewing the findings of previous reports, examining ESP case histories, and developing conclusions and recommendations for future studies.

One of the major achievements of the ESP in regard to benthic studies was the characterization of benthic habitats of the U.S. continental shelves. In most instances, however, sites were sampled only infrequently or for too short a period, so there is little understanding of temporal and spatial variability. As discussed by Rabalais and Boesch (1987), benthic surveys of the OCS revealed highly diverse oceanographic and biological conditions. Marine ecosystems are complex, open, and dynamic (Boesch et al., 1987), and interpretation of the environmental effects of anthropogenic activities is therefore extremely difficult. Temporal and spatial variation occurs at all levels of the ecosystem, and predictable patterns of resilience and recovery from perturbations are difficult to discern.

Descriptions of the dominant features and processes of the continental shelf environments of the United States constitute an adequate basis for defining research efforts directed at understanding the processes governing shelf environments and evaluating the impacts of environmental perturbations. The continental shelf environments of the United States range over 48° latitude and extend from polar seas to nearly tropical waters. The continental shelf regions of the United States discussed by Rabalais and Boesch (1987) are presented in Table 3-6 with MMS's planning regions for comparison.

Each of the regions is characterized by rather distinct oceanographic, geological, and biological characteristics. Because the biological systems usually reflect the physical forces and the geological substrata, it is critical that the abiotic characteristics of each region be understood. The dominant physical oceanographic features of U.S. continental shelves were discussed in an earlier report on physical oceanography (NRC, 1990a), and the biotic and abiotic features of these environments were discussed in detail by Rabalais and Boesch (1987). Those works make it clear that much is known about the geological and biological characteristics of each of the shelf environments.

TABLE 3-1 Features and Processes of U.S. Continental Shelf Areas—Shelf Morphology, Sedimentary Regimes, and Depocenters

Region	Shelf morphology	Stage of sedimentary evolution	Sedimentary regime	Depocenters
New England	Dominated by shallow plateau (Georges Bank) bordered by deeper channels; Gulf of Maine with irregular bedrock and basins; large sand shoals and waves of Nantucket Shoals; shelf edge incised by submarine canyons	Autochthonous	Low depositional, dominantly sands with gravels in areas, sand shoals and waves in shallower areas, grade to medium to fine sands mid shelf	Major area SW of Georges Bank, "Mud Patch," heads of submarine canyons, some eventually to Long Island Sound
Middle Atlantic Bight	Broad, gently sloping platform with complex mesoscale topography of ridges and smaller sand waves, sediment-filled channels	Autochthonous	Low depositional, dominantly sands >75%, mostly >90%, fine-grained sediments generally absent except for some accumulation in depressions	Deposited in salt marshes and estuaries or carried to shelf edge, slope, and heads of submarine canyons
South Atlantic Bight	Broad, gently sloping platform with cross-shelf shoals, sand waves, rocky outcrops; calcareous reefs at shelf break; no submarine canyons	Autochthonous	Low depositional, coarse to medium sands with finer sands at depth, little fine fraction except in cape-associated "shadows"	Deposited in marshes and estuaries or carried to shelf edge
West Florida Shelf	Broad, gently sloping platform of carbonate sand sheet with subsurface or low relief exposed hard strata at mid and outer shelf and algal nodule areas at shelf break	Autochthonous	Predominantly sands with little fine fraction, some areas of finer sediments nearshore, mid shelf and near Florida Keys	Off shelf and into Florida current, may be removed from shelf area
North Central Gulf of Mexico	Broad, gently sloping shelf except at Mississippi River prodelta and De Soto Canyon; ridges and pinnacles on outer shelf and at shelf break	Autochthonous/ Allochthonous	Quartz sand sheet with increasing fine fraction towards Mississippi River prodelta and off major estuaries	Mississippi River prodelta, sounds, off Mobile Bay, also to outer shelf of West Florida shelf
Northwestern Gulf of Mexico	Gently sloping, wide shelf with relict shorelines, distributary ridges, relict reefs and numerous diapirs on shelf, shelf break and slope; very wide, hummocky slope	Allochthonous/ Climax Grading	Sand decreases and silt increases seaward; patchy occurrence of sand areas, increase in clay W of delta, poorly to very poorly sorted sediments inshore	Mississippi and Atchafalaya deltas and prodeltas, outer shelf and slope
South Texas	Gently sloping, wide shelf with deltaic bulges at Rio Grande and off Matagorda Island with broad, ramp-like indentation between; relict shorelines and reefs, sediment-filled channels, diapirs on shelf	Climax Grading	Mostly silty sands with decrease in sand and increase in silt offshore, patches of sands on ancient deltas, higher clay content in area mid shelf off Port Aransas	Bays, outer shelf and slope

Region	Shelf morphology	Stage of sedimentary evolution	Sedimentary regime	Depocenters
Southern California	Narrow shelf, complex borderland with southeast-northwest trending ridges and basins, shallow rocky banks at shelf edge, indentation by submarine canyons	Climax Grading	Progrades from sands to silty sands to sandy silts and then silts at shelf edge, more complex sediments around rock outcrops	Deposition mostly in nearshore basins and on slopes but also in outer basins
Central and Northern California	Narrow, gradually sloping shelf incised by several submarine canyons along entire length, bands of bedrock habitats on inner shelf, rock outcrops on outer edge of basins at shelf edge	Climax Grading/ Allochthonous	Coarser, sandy sediments nearshore to finer silts and clays offshore, fine sediments between Eel and Klamath Rivers and off Russian River	Submarine canyons and slopes
Washington-Oregon	Narrow, gradually sloping and generally featureless shelf, some major submarine canyons incise shelf	Climax Grading/ Allochthonous	Inner shelf sands to 60 m, mid-shelf silts to 120 m, some sandy areas near canyons	Mid-shelf sediments of silt similar to Columbia River suspended load
Bering Sea	Broad (>500 km), gently sloping marginal shelf in SE to broad, shallow epicontinental shelf in NE; relatively flat and featureless in SE, undulating hummocky in W, modern and relict sand ridges and shoals in NE, prograding Yukon delta in Norton Sound	Climax Grading, SE; Autochthonous, N; Allochthonous, Norton Sound	Fine-grained transgressive sands with decrease in sands offshore in SE; glacial gravel and transgressive sands in W; thin transgressive sands facies in N, nondepositional; thick, muddy deposits in Norton Sound	Major center in southern Chukchi Sea for Yukon-derived sediments, also eastern sector of Norton Sound, localized areas on southeastern shelf
Alaskan Arctic	Broad, gently sloping marginal shelf in Chukchi Sea to very narrow shelf in Beaufort Sea; little bathymetric relief except for Barrow Sea Valley and Hanna Shoal in Chukchi Sea	Climax Grading	Majority of Chukchi Shelf with 5ϕ sediments; Beaufort shelf with primarily sandy muds and silt and clay at shelf edge, gravels at shelf break, some input from river run-off, tundra slumping, and river ice	Low sediment transport nearshore and predominantly westward, possible depositional site in SW Harrison Bay for Colville River delta muds
Gulf of Alaska	Broad, gently sloping marginal shelf, dynamic bedforms of sand waves (8 to 15 m high); major submarine valleys and basins in NE, series of flat banks (50 to 100m) and troughs down to 200 m off Kodiak	Autochthonous/ Climax Grading	Mostly reworked glacial off Kodiak, shelly sands nearshore, coarse sediments on banks, fine in troughs; silts/clays and high sedimentation rates inshore in NE, sand and gravel mixed with silts and clays at shelf break	Troughs off Kodiak (except Stevenson), volcanic ash as indicator of present day dispersal patterns; removed from shelf and slope in NE

Source: Adapted from Rabalais and Boesch, 1987.

TABLE 3-2 Tidal and Wave Climates, Physical Processes and Benthic Boundary Layer Dynamics

Region	Tides	Wave climate	Dominant processes and events	Benthic boundary layer dynamics
New England	Semidiurnal of moderate magnitude, 4 m at mouth of Bay of Fundy; tidal current 30-40 cm/s in channels, >55 cm/s on Georges Bank proper	30-40% of waves >1.5 m, 50% of waves > 1 m	Constant reworking by fast tidal currents and waves down to 60 m, winter storms	Surficial sediments under almost constant scour, dynamic sand waves, low suspended particles over Georges Bank, 750-800 μg/l over mid shelf, 250 μ/l over outer shelf
Middle Atlantic Bight	Semidiurnal of moderate magnitude; tidal current <25 cm/s	~30% of waves >1.5 m, ~5-10% of waves >3.5 m	Wind-influenced currents on inner shelf, storm-wave generated currents affect outer shelf, winter storms	Ripple marks down to 200 m, winter storms main cause of disturbance >60 m, more frequent disturbance <60 m by winds and tidal currents; sand waves not active
South Atlantic Bight	Semidiurnal of moderate magnitude; tidal current <25 cm/s	Nearshore waves <0.5 m, ~20% of waves >1.5 m, ~5% of waves >3.5 m	Tidal currents and wind regimes affect depths to 20 m, freshwater inflow off Georgia and S. Carolina, hurricanes, Gulf Stream intrusions	Evidence of ripple marks in <20 m, no active sand waves
West Florida Shelf	Predominantly diurnal, but mixed and semidiurnal, low magnitude 0.3-1.2 m; tidal currents generally <8 cm/s	Generally low, most 0.3-1.3 m (summer-winter)	Seasonal wind-generated currents and waves, hurricanes, winter frontal passages	Localized turbidity fronts, seasonal sand ripples, near-bottom nepheloid layers influenced by storms, frontal passages, bottom currents; strong nepheloid layer at mid shelf
North Central Gulf of Mexico	Predominantly diurnal, but mixed and semidiurnal low magnitude 0.3-1.2 m; tidal currents generally <8 cm/s	Generally low wave regime, most 0.5-1.0 m (summer-winter)	Seasonal wind-generated currents and waves, particularly in winter, high frequency of hurricanes, winter frontal passages	Spring turbid bottom waters (surface also) near Mississippi River, water column turbid whole depth in winter
Northwestern Gulf of Mexico	Diurnal and mixed, low magnitude 0.5-1.5 m; tidal currents low, ≤14 cm/s	Low wave regime 0.5 m in summer to 1.0 m in winter, historical maximum of 7.3 m in summer	River discharge, inshore effects as far west as Galveston, wind-generated currents and waves, high frequency of hurricanes, winter frontal passages, widespread seasonal hypoxia	Nepheloid layers and turbidity currents, near-bottom nepheloid layer present all seasons except winter, in <20 m associated with wind-generated currents
South Texas	Mixed diurnal and semidiurnal, low magnitude 0.4-0.5 m; tidal current velocity ≤14 cm/s	Low wave regime, most 0.9-1.8 m; summer, most 0-0.6 m; winter, most 1.2-1.8 m; waves up to 2-3 m in hurricanes	Persistent SE winds predominate, along with winter northerly winds cause wind-generated currents and waves, high frequency of hurricanes, winter frontal passages	Near-bottom turbidity all seasons, variable in thickness and distribution, related to thermal mixing, internal waves, nearshore suspension by waves and tidal mixing
Southern California	Mixed semidiurnal, of moderate magnitude, 0.3-2.5 m	Average significant wave heights 1-2 m, tsunamis with waves of 6.3 m	Wind-generated nearshore water movements, prevailing winds from NW (16-32 km/hr), more onshore in summer, spring, and summer upwelling, occasional small tsunamis, periodic El Niño events, seismicity	Sediment erosion from exposed shallow shelf with deposition in basins of southern California borderland

Region	Tides	Wave climate	Dominant processes and events	Benthic boundary layer dynamics
Central and Northern California	Mixed semidiurnal of moderate magnitude, 0.3-2.3 m	Average significant wave heights of 1-3 m, storm waves of 5-11 m, tsunamis with waves of 6.3 m	Severe extratropical winter storms, moderate storm surges of 0.5-1 m more common, spring and summer upwelling, occasional tsunamis, seismicity	Winter storm dominated sedimentary regime with sediment deposition off major northern California rivers
Washington-Oregon	Mixed semidiurnal of moderate magnitude, up to 3 m in spring off Oregon	Average wave heights greater than to south, tsunamis with waves of 6.3 m	Severe extratropical winter storms, spring and summer upwelling, occasional tsunamis	Mid-shelf silt deposits transient and undergo repeated resuspension and redeposition by storm-induced bottom currents
Gulf of Alaska	Mixed semidiurnal, mean range at Kodiak 0.9-3.3 m, in NE 2-4 m; swift tidal current in Cook Inlet averages 300 cm/s	High waves in storms (9 m and higher), 3 m waves prevalent in winter, maximal tsunami waves up to 33 m	Extreme storm conditions with winds up to 160 km/hr, floe ice and pack ice in Cook Inlet in winter, tsunamis, seismicity and volcanism	In general, little suspended matter due to strong currents and winter storm waves which prevent sediment accumulation, water exiting Cook Inlet with high suspended sediments (5-200 mg/l) which flows into Shelikof Strait
Bering Sea	Mixed semidiurnal tides with marked diurnal inequalities; in southern area near peninsula and land restrictions up to 5 m, in NE tides <0.5 m	Larger waves in SE up to 10-20 m, lower in NE up to 7 m, maximum wave heights 32 m, waves most influential in shallow Norton Sound and Bristol Bay	Severe storms may double strength of wind-generated currents and waves, N-S differences in storms; ice movements, dense coverage, ice presence, N-S differences; tsunamis in North Aleutian shelf; potential seismicity and volcanism	In NE, major storm surges every several years resuspend and transport sediments; dynamic sediment transport by ice gouging, storm waves, and ice loading
Alaskan Arctic	Mixed semidiurnal tides with mean range of 10 to 30 cm, small tidal currents of 0.3-0.5 cm/s	Extreme storm waves not as likely as in Bering Sea or Gulf of Alaska because generation hampered by pack ice, 2.5 m waves during storms, only 22% >0.5 m	Severe storms with high winds but waves tempered by sea ice, gouging by offshore pack ice, offshore subsea permafrost, active ice flow lead along Chukchi Sea coast, coastal erosion on Beaufort Sea coast	Storm-affected sediments in Chukchi Sea, ice gouging on seabed out to 60 m in whole area; low coastal sediment transport inshore on Beaufort Shelf, some reworking of coarse sediments by hydrodynamic forces on inner and central shelf

Source: Adapted from Rabalais and Boesch, 1987.

TABLE 3-3 Temperature Regimes, Biogeographic Affinities, and Literature References to Benthic Studies

	Bottom temperature regime (winter °C to summer °C)				
Region	Inner shelf	Outer shelf	Shelfbreak	Benthic studies	Biogeographic affinities
New England	0.5-4° to 10-12°	4-5°-~8°	10°	Wigley, 1965; Wigley & McIntyre, 1964; Wigley & Theroux, 1976, 1981; Maurer & Lethem, 1981a,b; Michael, 1977; Michael et al., 1983; Battelle/WHOI, 1983, 1984	Boreal or cold water assemblage
Middle Atlantic Bight	1-4° to 14-17° with latitudinal differences	5-8° to 13-14°	10-12°	Gross, 1976; Wenner & Boesch, 1979; Schaffner & Boesch, 1982; Boesch & Bowen, in press	Transitional between cold water assemblage to north and warm, temperate south of Cape Hatteras, shallow water Carolinian affinities, offshore boreal affinities
South Atlantic Bight	6-10° to 28° with latitudinal differences	12-17° to 26-27° with latitudinal differences	15-17° [14-21°]	Williams et al., 1968; Day et al., 1971; Tenore, 1979; Herbst et al., 1979	Warm, temperate Carolinian affinities inshore with subtropical and tropical affinities offshore
West Florida Shelf	20 to 26° with latitudinal differences	20° to 24° with latitudinal differences	16° to 22° with latitudinal differences	State Univ. Syst. Flor., 1977; Dames & Moore, 1979; Woodward-Clyde & Cont. Shelf Assoc., 1983; Lyons, 1980; Collard & D'Asaro, 1973; Lyons & Collard, 1974	Shallow shelf with Carolinian affinities, deep shelf with West Indian/tropical affinities
North Central Gulf of Mexico	~12-15° to 29°	~18-19° to 21-25°	~19° to 22°	State Univ. Syst. Flor., 1977; Dames & Moore, 1979; Lyons & Collard, 1974	Warm, temperate Carolinian affinities, separated by some from northern Gulf W of Mississippi River, outer shelf tropical affinities
Northwestern Gulf of Mexico	15-16° to 27-28°	18-19° to 21-25°	19-20° to 22°	Ward et al., 1979; Bedinger, 1981; Middleditch, 1981; Jackson, 1977; Hann & Randall, 1980; DeRouen et al., 1982	Warm, temperate Carolinian affinities, separated by some from northern Gulf E of Mississippi River, outer shelf tropical affinities
South Texas	14-15° to 28° with latitudinal differences	15-17° to 25° with latitudinal differences	19-22° with latitudinal differences	Holland 1977, 1979; Flint, 1981; Flint & Holland, 1980; Flint & Rabalais, 1980a,b, 1981	Mostly warm, temperate Carolinian affinities with more subtropical influence, considered by some as Texas transitional between temperate and tropical outer shelf tropical affinities
Southern California	12-14° to 17-19.5° with latitudinal differences	10-13° to 15-17°	10-13° to 15-17° @ 200m 8-9° throughout year	Jones, 1969; Barnard & Hartman, 1959; Barnard, 1963; Fauchald & Jones, 1977, 1978; Balcom, 1981	Transitional between southern subtropical Panamanian province and northern temperate Oregonian province

Region	Bottom temperature regime (winter °C to summer °C)			Benthic studies	Biogeographic affinities
	Inner shelf	Outer shelf	Shelfbreak		
Central and Northern California	10° to 14° with latitudinal differences	9-10° to 12-13°	9-10° to 12-13°	Jones & Stokes Assoc., Inc., 1981	Temperate, Oregonian province
Washington-Oregon	9-10° to 12-13°	9-10° to 12-13°	9-10° to 12-13°	Carey, 1972; Lie & Kelley, 1970; Lie & Kisker, 1970; Richardson et al., 1977	Temperate, Oregonian province
Gulf of Alaska	<2° in May, 1-2° to 6-9° in <100 m over shoals on Kodiak where water nearly isothermal	2-3° in May	4-5° throughout year at Kodiak shelf break	Feder and Matheke, 1979; Feder & Jewett, 1980	
Bering Sea	<-1.5 to 8-10° with latitudinal and depth differences	-1-0° to -1-2° with latitudinal differences	1-3° to 2-4° with latitudinal differences	Hood & Calder, 1981; Stoker, 1981; Haflinger, 1981; Feder & Jewett, 1981; Nelson et al., 1981	Primarily boreal Pacific
Alaskan Arctic	-1-4° in summer to -1° in fall with most values at -1-10°	2° in summer to -1.5° in fall	0° in summer to -1° in fall	Carey et al., 1974, 1984; Carey & Ruff, 1977; Bilyard & Carey, 1979, 1980; Broad et al., 1981; Stoker, 1981	Primarily boreal Pacific in Chukchi with more Arctic species than Bering Sea; dominance of amphiboreal species in Beaufort, many also occur in temperate or tropical latitudes, or both

Source: Adapted from Rabalais and Boesch, 1987.

In addition to providing valuable support for descriptive studies of U.S. continental shelf habitats, the ESP has contributed to our understanding of marine biogeography, animal-sediment relationships, and the importance of shelf ecosystems in food-chain dynamics. In recent programs, the fate of chemicals in continental shelf habitats (Bothner et al., 1983; Boehm and Farrington, 1984; Boehm, 1987; Boehm et al., 1987; Boehm et al., 1990), the interaction of biological and physical processes in benthic environments and bottom boundary layer processes (Battelle/WHOI, 1983; Butman and Moody, 1983), and the effects of exploratory drilling (Neff et al., 1989) have been examined. Through both ESP and the National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program (NOAA/OCSEAP) efforts, advances in analytical chemistry have been achieved for assessing low-level contamination associated with discharges of oil and gas exploration and production (MacLeod et al., 1979, 1980, 1982, 1984, 1985, 1988; Krahn and MacLeod, 1982; Malins et al., 1984).

In summary, the ESP has succeeded in characterizing OCS frontier areas of interest for oil and gas development, although not to the point where temporal and spatial variability could be discerned; demonstrating that these areas are relatively uncontaminated with trace metals and petroleum hydrocarbons, but in some instances slightly contaminated by other

TABLE 3-4 Dominant Benthic Assemblages

	Dominant macrofauna		
Region	Inner shelf	Outer shelf	Shelf break
New England	60 m-top of bank: *Tellina agilis* (b), *Pseudunciola*, *Protohaustorius* (a), *Polygordius*, *Exogene*, *Hebes, Spiophanes* (p), *Echinarachnius* (ecd)	80 m: syllid polychaetes, *Phallodrilus* (o), *Unciola, Erichthonius, Byblis* (a)	Paraonid, capitellid, cirratulid polychaetes, *Ampelisca* (a); in another study: *Pseudohaustorius, Protohaustorius, Trichophoxus* (a)
Middle Atlantic Bight	~20-30 m, dynamic sands: interstitial feeders, *Tanaissus* (t), *Polygordius, Goniadella, Lumbrinerides* (p)	~40-100 m: fewer interstitial feeders and more amphipods, *Unciola, Ampelisca, Erichthonius, Photis, Rhepaxinius* (a), *Spiophanes, Goniadella, Lumbrinerides, Euchone, Lumbrineris* (p)	~110-200 m: increase in burrowers and subsurface deposit feeders, *Onuphis, Lumbrineris, spiophanes, Aricidea* (p), *Harbansus* (os), *Amphioplus* (op), *Ampelisca, Unciola* (a)
South Atlantic Bight	<40 m "turbulent zone": *Paleanotus, Polygordius, Lumbrineris* (p), *Protohaustorius, Maera* (a)	40-124 m, more quiescent zone: *Onuphis, Spiofillicornis, Chaetozone, Pomatoceros* (p), *Siphonocoetes* (a)	160-205 m: *Odontosyllis, Onuphis, Lumbrineris, Prionospio, Chaetozone* (p), *Paraphoxus, Unciola* (a), *Nucula* (b)
West Florida Shelf	>40 m: *Fabrica, Vermiliopsis, Prionospio, Hydorides, Lumbrineris, Goniadides, Ehlersia* (p), *Photis, Maera* (ga), *Cyclaspis* (cu), *Phtisica* (cp), *Lucina* (b)	40-100 m: *Magelona, Ceratocephale, synelmis, Schistomeringo, Tharyx, Prionospio, Ampharete* (p), *Lucina* (b), *Selenaria* (br)	100 m: *Glycera, Prionospio, Synelmis, Trebellides* (p)
North Central Gulf of Mexico	Not delineated	Dominants for entire shelf: *Syllis, Sphaerosyllis, Websterinereis, Glycera, Lumbrineris, Prionospio, Paraprionospio, Mediomastus* (p)	Not delineated
Northwestern Gulf of Mexico	*Lumbrineris, Paraprionospio, Magelona, Sigambra, Diopatra* (p), *Golfingia* (s), *Ampelisca* (a)	*Cossura, Ninoe, Nephtys, Notomastus, Lumbrineris, Paraprionospio* (p), *Corbula, Nuculana* (b), *Volvulella* (g)	No shelf break stations
South Texas	~15-30 m: *Magelona, Nereis, Mediomastus, Aricidea, Prionospio, Paraprionospio* (p), *Tellina* (b), *Ampelisca* (a)	~40-90 m: *Paraprionospio, Cossura, Nephtys, Paraonis, Magelona, Asychis, Notomastus, Mediomastus* (p), *Ampelisca* (a), Apseudes (t), *Eudorella* (cu)	~100-135 m: *Paralacydonia, Tharyx, Stenaspis, Paronis, Sigambra* (p), *Xenanthura* (i), *Amygdalum, Nuculana, Pitar* (b), *Alternochelata* (os)
Southern California	<25 m, dynamic sands *Sipunculus* (s), *Loimia Ophelia, Nephtys, Nothria, Prionospio, Diopatra* (p), *Tellina* (b), *Amphipholus* (op), *Diastylopsis* (cu), *Paraphoxus* (a)	28-109 m: *Pectinaria* (p), *Heterophoxus, Paraphoxus, Westwoodilla* (a), *Parvilucina, Tellina* (b), *Euphilomedes* (os), *Amphiodia* (op), *Diastyllis* (cu), *Listriolobus* (ech)	161-620 m: *Pectinaria, Prionospio, Madane* (p), *Ampelisca* (a), *Limifossor* (g), *Allocentrotus, Brissopsis* (ecd), *Amphiodia* (op), *Cyclocardia* (b)

anthropogenic activities; and improving our understanding of the minimal effects of exploratory drilling on shelf habitats (although to a large extent studies of the toxicity and sublethal effects of exploratory drilling were supported by industry and other federal agencies).

	Dominant macrofauna		
Region	Inner shelf	Outer shelf	Shelf break
Central and Northern California	Sands of shallow shelf: *Diopatra, Nothria* (p), *Dendraster* (as), amphipods	Not delineated	Not delineated
Washington-Oregon	~35 m, inner shelf sands: *Diastylopsis* (cu), *Ampelisca, Paraphoxus* (a), *Tellina, Macoma* (b), *Owenia, Nephtys,* C*haetozone* (p)	~95 m, intermediate shelf sands: *Magelona, Sternaspis, Nephtys, Haploscoloplos (p), Yoldia, Macoma, Axinopsida* (b), *Paraphoxus* (a)	~150 m deep-water muds: *Prionospio, Sternaspis, Ninoe* (p), *Axinopsida, Adontorhina, Macoma* (b), *Heterophoxus* (a), *Brisaster* (ecd), *Ophiura, Amphioplus* (op)
Gulf of Alaska	NE: inshore, deposit feeders (worms) predominate (61-65% of sample), *Nucula, Nuculana, Yoldia, Thyasira, Axinopsida* (b), *Terebellides, Nereis, Lumbrineris, Sternaspis* (p), *Heterophoxus* (a), C*haetoderma* (ap), *Diamphiodia* (op)	Same as inner and mid shelf	NE shelf break and slope, more suspension feeders (clams), comprise 32% of sample, deposit feeders 26%, *Notoproctus, Glycera,* Sabellids, syllids (p), sipunculids, brachiopods, *Astarte* (b), *Anonyx* (a)
Bering Sea	*Byblis, Ampelisca* (a), *Capitella, Ampharete, Haploscoloplos, Myriochele, Sternapsis* (p), *Cylinchna* (g), *Serripes (b), Diamphiodia, Gorgonocephalus* (op)	*Axinopsida, Tellina, Yoldia, Clinocardium* (b), *Byblis, Bathymedon, Protomedeia* (a), *Capiella, Haploscoloplos, Brada, Artacama* (p), *Echinarachnius* (ecd), *Chaetoderma* (ap)	*Aricidea, Glycera, Asabellides, Harmothoe, Maldane* (p), *Ampelisca* (a), *Ophiura* (op), *Golfingia* (s), *Astarte, Hiatella* (b)
Alaskan Arctic	In Chukchi similar to Chukchi outer shelf; in Beaufort, inshore zone <20 m, polychaetes, gammarid amphipods, isopod, bivalves, priapulid	Chukchi: *Maldane* (p), *Astarte, Macoma, Nucula, Yoldia* (b), *Ophiura* (op), *Golfingia* (s), *Pontoporeia* (a); Beaufort: offshore zone (20-200 m), fauna not delineated	In Chukchi, similar to outer shelf, in Beaufort, not studied

NOTE: Abbreviations for taxa are: a—amphipod, ap—aplocophoran, as—asteroid, b—bivalve, br—bryozoan, cu—cumacean, ca—caprellid, ecb—echiuran, ecd—echinoid, g—gastropod, ga—gammarid amphipod, i—isopod, o—oligochaete, op—ophiuroid, os—ostracod, p—polychaete. Source: Adapted from Rabalais and Boesch, 1987

Shortcomings of the Environmental Studies Program

In spite of detailed characterizations, it is difficult to determine the vulnerability of shelf ecosystems to OCS activities and the recovery of the ecosystems (Rabalais and Boesch, 1987). Although the relative sensitivities of coastal habitats to oil spills have been evaluated (Gundlach and Hayes, 1978; Owens and Robilliard, 1981), little effort has been spent on comparing the sensitivities of shelf habitats or assessing OCS impacts other than oil spills.

TABLE 3-5 Other Benthic Assemblages

Region	Macrofaunal variability	Epifaunal predators	Hard substrates and rare habitats
New England	Regional stations distinct by depth and sediment type across seasons during two years, little seasonal variability with differences not repeatable over two years	Gadid fishes, flatfishes, cancroid crabs, starfish	Epibenthic and soft coral communities at heads of submarine canyons
Middle Atlantic Bight	Variability related to mesoscale topography, bathymetric gradients related to temperature, temp. variability, frequency and magnitude of sediment disturbance, variability of population and community structure decreases with depth	Gadid fishes, flatfishes, cancroid crabs, starfish	Epibenthic and soft coral communities at heads of submarine canyons
South Atlantic Bight	High seasonal variability and year-to-year differences nearshore, variability with depth related to frequency and magnitude of sediment disturbance as well as sediment distribution		Shallow coral patches near shore, calcareous reefs at shelf break, scleratinian coral reefs at shelf break off Florida
West Florida Shelf	Seasonal differences in community structure, particularly nearshore, faunal differences related to bathymetry and sediment distributions	Penaeid and sicyonid shrimp, portunid crabs, sea basses, flatfishes, holothurians (bioturbation)	Numerous hard substrates with epibenthic fauna and hermatypic corals, algal nodule substrates, nearshore seagrass beds, Florida Middle Grounds
North Central Gulf of Mexico	Seasonal differences with decreases in polychaete taxa and density and crustacean density in winter, variability in polychaete density with depth related to sediment differences	Penaeid and sicyonid shrimp, portunid crabs, sciaenid fishes, flatfishes	Exposed hard substrate areas on outer shelf and at shelf break
Northwestern Gulf of Mexico	Seasonal changes in abundance and dominance, variability in community structure related to sediment differences both with depth and physiography and to seasonal hypoxia on inner shelf	Penaeid shrimp, portunid crabs, sciaenid fishes, flatfishes	Exposed salt dome banks of carbonate sediments on outer shelf and shelf break, many with hermatypic corals, most with top environmental priority ranking, East and West Flower Gardens
South Texas	Some seasonal differences but not consistent over depth or latitude gradients, large-scale community differences related more to sediment distributions and hydrographic variability	Penaeid shrimp, portunid crabs, sciaenid fishes, flatfishes	Exposed salt dome banks of carbonate sediments on outer shelf, most with low diversity epibenthic communities, most with low environmental priority ranking
Southern California	Seasonal recruitment shown by aggregations of *Amphiodia* in summer on mainland shelf, no apparent seasonality in basins; large-scale differences related to complex topography	Sea basses, sciaenid fishes, sea urchins and starfish, cancroid crabs, pandalid shrimp	Scattered submerged ridges and topographic highs in complex borderland, rocky banks at shelf edges, some in shallower water with purple coral (*Allopora*), others with rich epibiota; kelp forests, Tanner and Cortez Banks

Region	Macrofaunal variability	Epifaunal predators	Hard substrates and rare habitats
Washington-Oregon	Increases in density, diversity and standing stock with depth	Cancroid crabs, flatfishes, rock fish	
Gulf of Alaska	In NE, east/west differences, increase in diversity at shelf break, differences in community structure related to sediment differences and sedimentation rate	Lithodid and cancroid crabs, pandalid shrimp, flatfishes, sea urchins and starfish	Area of bedrock extending from Kayak Island to 200 m, gravel areas at shelf break with communities similar to those of hard substrate areas
Bering Sea	No seasonal or annual standing stock differences over 5 years, "relatively stable"; most nearshore/ offshore differences or large-scale differences related to sediment distributions, latitudinal differences related to sea ice dynamics	Lithodid crabs, pandalid shrimp, flatfishes, codfish, starfish, marine mammals	Yukon River delta area
Alaskan Arctic	In Chukchi, no seasonal or annual standing stock differences over 5 years, "relatively stable"; in Beaufort, longitudinal variability related to warmer Bering-Chukchi water in W and E-W sediment differences, seaward differences related to sea ice dynamics	Whitefish, cisco, grayling, arctic char, arctic cod, flatfishes, sculpin, marine mammals	Boulder areas on inner shelf with epibiotic communities, Boulder Patch in Stefansson Sound, kelp forests, Colville River delta area

Source: Boesch and Rabalais, 1987.

Rabalais and Boesch (1987) concluded that four features of continental shelf habitats could be used for a comparative evaluation of habitat sensitivities:

- Sedimentary regime, with depositional areas being the ultimate repository of particle-bound contaminants.
- Temperature, which controls rates of both biodegradation and recolonization by benthic organisms.
- Depth, which influences rates of recolonization and recovery after disturbance.
- Biogenically structured communities, where species interactions control the recovery, e.g., coral reefs, mangroves.

To a large extent, benthic studies have been largely descriptive, or observational and, because of design inadequacies, have failed to increase our ability to predict impacts on the OCS. Carney (1987) concluded that the inadequacies of many benthic surveys resulted from the lack of an operational definition and understanding of potential impacts, the lack of a stated hypothesis for delineating impacts and distinguishing impacts from natural variation, and a failure to use appropriate statistical techniques for population surveys.

Too little emphasis has been placed on process-oriented studies, including studies of sediment dynamics, trophic interactions, recruitment mechanisms, and biogeochemical cycling. With the exception of data from recent studies in the north Atlantic, California, and the Beaufort Sea, OCS frontier areas lack sufficient data to support predictions of the long-term fate and effects of operational discharges or an understanding of large-scale consequences of changes in benthic populations.

TABLE 3-6 Continental Shelf Regions of the United States Compared with Planning Areas of MMS.

Region	Coastal boundary	MMS offshore planning areas
ATLANTIC COAST		
New England		North Atlantic
	Montauk Point	
Middle Atlantic Bight		Middle Atlantic
	Cape Hatteras	
South Atlantic Bight		South Atlantic
GULF OF MEXICO		
West Florida Shelf		Eastern Gulf
	Cape San Blas	
North Central Gulf of Mexico		Eastern Gulf (in part)
	Louisiana-Mississippi border	
Northwestern Gulf of Mexico		Central Gulf Western Gulf (in part)
	Matagorda Bay	
South Texas		Western Gulf
PACIFIC COAST		
Southern California		Southern California
	Point Conception	
Central and Northern California		Southern California (in part)
		Central-Northern California
	California-Oregon border	
Washington-Oregon		Washington-Oregon
ALASKA		
Gulf of Alaska		Gulf of Alaska
		Kodiak
		Cook Inlet
		Shumagin
	Aleutian Islands	
Bering Sea		North Aleutian Basin
		St. George Basin
		St. Matthew Hall
		Navarin Basin
		Norton Basin
	Bering Strait	
Alaskan Arctic		Hope Basin
		Chukchi Sea
		Beaufort Sea

Source: Adapted from Rabalais and Boesch, 1987.

The ESP has focused mostly on frontier areas of the OCS to provide baseline information for lease sales. But analyses of potential long-term effects of OCS activities have concluded that the most important impacts are expected to occur during development and production, and not during exploration (Boesch et al., 1987). A greater balance should be achieved between studies conducted in frontier areas and studies conducted in areas where development and production are occurring (e.g., northwestern Gulf of Mexico) or are likely to occur. MMS should expend more resources on examining benthic communities on the shelf slope and rise (i.e., within the 200 mile EEZ). The panel notes that a preliminary survey has been done on the slope of the Gulf of Mexico (Gallaway, 1988). Greater attention should also be placed on characterizing the impacts of all operational discharges from OCS activities. The effects of drilling-fluid discharges have been reviewed extensively (NRC, 1983); water-based drilling fluids used in U.S. OCS areas are relatively nontoxic and pose little long-term or large-scale risks to benthic systems. Little attention has been focused on the fate and effects of produced waters, a potentially more important source of toxic contaminants.

A final shortcoming of the ESP is a lack of continuity in technical expertise from one study to the next. That seems to be a result of the infrastructure of MMS's "procurement" approach, rather than a research-and-development approach, to program administration.

Design of Benthic Monitoring Programs

Ecologists in all disciplines have long recognized the importance of good time-series data. They have produced powerful and unexpected insights into oceanic systems. In each case, a particular goal was initially instrumental in setting up long-term sampling programs, but each program yielded convincing and important results that illustrate the power of even crude time-series data in testing hypotheses and predictions. Furthermore, the data base for each has provided new and nonintuitive insights into the functioning of ocean systems; they are particularly useful in establishing the importance of physical forcing of biological events. Although such studies have usually been harmed by struggles over financing, the power of time-series data is so great that even studies flawed by budget cuts have contributed to our understanding.

A major problem in benthic ecology is understanding the factors that influence the dispersal and local abundance of the long-lived pelagic larvae typical of most benthic invertebrates. Many instances of strong, episodic benthic recruitment almost certainly result from large-scale variation in larval abundance or dispersal processes. Those episodes represent the normal state of affairs for large, long-lived benthic species, such as flatfishes, crabs, lobsters, abalones, and most echinoderms. The patterns of distribution revealed by large-scale benthic studies result from episodic recruitment; it is important to recognize that episodic recruitment must be evaluated in decades, rather than years. Thus, long-term programs like the California Cooperative Fisheries Investigations (CalCOFI) program, but with appropriate spatial and temporal resolution for benthic studies, would be useful in areas with active development and production, i.e., in the Gulf of Mexico and southern California (where the existing CalCOFI program should be strengthened).

Understanding Benthic Processes

It is insufficient for a monitoring program to document an effect without also providing an understanding of the mechanistic processes that produced the effect (Carney, 1987). Establishing mechanisms often requires some well-designed field or laboratory experiments to complement the monitoring process. Many variables are inextricably confounded in nature in such a way that their effects can be separated only through experimentation (Carney, 1987). Mesocosms (experimental setups larger than those typically found in indoor laboratories), flumes, or small experimental setups are potentially important in permitting observations of organism behavior and various biological interactions that are necessary to form a complete understanding of benthic processes. Mesocosms and other laboratory systems must be used appropriately, lest laboratory artifacts confound the results (Capuzzo, 1987; Underwood and Peterson, 1988). Although laboratory and mesocosm studies are restricted to studies of processes on smaller spatial scales, they provide a valuable link between field investigations by defining the biological and geochemical characteristics responsible for contaminant transport and effects. Furthermore, only through careful experimentation can complex interactions, such as nonadditive effects and higher-order interactions among variables, be detected and understood.

To measure the important variables on appropriate spatial and temporal scales, a conceptual model is needed of the hypothesized processes by which anthropogenic activities could be influencing the benthic biota. That might be self-evident, but such models are almost never used—an appalling omission. A monitoring program that is not linked to an assessment of various reasonable models of processes will gather data of very limited usefulness. For fuller evaluation of the processes by which anthropogenic activities influence the benthos of the continental shelf, modeling efforts should ultimately become numerical or analytical, at least for the physical processes of importance.

Biogeochemical Concerns

The transfer of contaminants derived from oil and gas activities on the continental shelf to marine biota depends on several factors that govern the fate of specific contaminant classes. Contaminants can accumulate in biological resources through aqueous, dietary, or sedimentary pathways, and the relative importance of each pathway depends on both chemical factors, such as compound solubility and adsorption-desorption kinetics, and biological factors, such as feeding habits and metabolism. For both trace metals and organic contaminants, factors that influence bioavailability must be resolved before uptake and potential damage to biota can be estimated (Boehm, 1987). Low-molecular-weight hydrocarbons and other partially oxidized organics found in produced waters are highly water-soluble and would be diluted rapidly on discharge. Uptake of those hydrocarbons by marine biota has been demonstrated (Armstrong et al., 1979), and the residence time of accumulated hydrocarbons can be much longer in marine biota than in the water column. Neff (1987) recently reviewed studies of the fate and effects of discharged drilling fluids and produced waters. He concluded that assessment of the importance of long-term exposure required more detailed characterization of the hydrocarbon and trace-metal composition of produced waters from different coastal and continental shelf sources. Accumulation of chemical components in the surface microlayer might result in the exposure of surface-dwelling eggs and larvae to high concentrations of toxicants (Hardy et al., 1987a,b).

The effect of oil spills on marine biota has been the subject of several recent reviews (NRC, 1985; Capuzzo, 1987; Spies, 1987). Data on several recent oil spills suggest that the medium- and higher-molecular-weight aromatic hydrocarbons, such as alkylated phenanthrenes and alkylated dibenzothiophenes, are among the most persistent petroleum hydrocarbons in both animal tissues and sediments (Grahl-Nielsen et al., 1978; Roesijadi et al., 1978; Teal et al., 1978;

Boehm et al., 1981, 1982; Farrington et al., 1982; Boehm, 1983). Thus, although short-term effects can result from acute exposure to a wide range of hydrocarbons, long-term chronic effects probably result from exposure to medium- and higher-molecular-weight aromatic hydrocarbons (Boehm, 1987), and the response of marine ecosystems to oil exposure has been linked to the persistence and degradation of these hydrocarbons. Data from oil spills—such as the West Falmouth oil spill (Sanders et al., 1980), the *Tsesis* oil spill (Elmgren et al., 1983), the *Amoco Cadiz* spill (Berthou et al., 1987), and the *Galeta* spill (Jackson et al., 1989)—confirm the relationship between the persistence of petroleum hydrocarbons and long-term recovery of benthic biota. Biological effects of oil spills and chronic petroleum discharges are greatest in low-energy environments from which physical removal of hydrocarbons is slow.

The ultimate fates of spilled petroleum or operational discharges depend primarily on the ability of microorganisms to use hydrocarbons as sources of carbon and energy (NRC, 1985). However, no crude oil is completely biodegradable. The polar fractions of petroleum and most molecular fractions that contain nitrogen, sulfur, and oxygen are essentially nonbiodegradable (NRC, 1989b). The paraffinic fractions are readily degradable under ideal conditions (Payne et al., 1987). The absolute amount and rate of biodegradation of any petroleum depend on its composition and the specific abiotic environmental conditions.

Microorganisms capable of degrading a variety of petroleum hydrocarbons are widespread in aquatic environments (Atlas et al., 1981; Bauer and Capone, 1988). In response to the *Amoco Cadiz* oil spill off the coast of France, microbial populations changed in their ability to degrade hydrocarbons (Ward et al., 1980). Similarly, the numbers of hydrocarbon-degrading bacteria vary by several orders of magnitude among sites sampled after the *Exxon Valdez* oil spill (Brown and Braddock, 1990). Several studies cited by Bartha and Atlas (1987) in their extensive review of hydrocarbon metabolism by microorganisms showed positive correlations between the numbers of hydrocarbon-degrading microorganisms and oil-pollution patterns.

In general the rate of petroleum biodegradation in marine waters is not limited by oxygen or temperature, but rather by the availability of inorganic nutrients. The most toxic low-molecular-weight aromatic fraction of crude oil in the water does not generally persist long. However, although a "light transparent fuel oil" spilled in 1969 became invisible within days, chemical analyses could detect fractions of the oil in the water for up to 8 months (Blumer et al., 1971).

In nutrient-rich (organic) marine sediments, oxygen concentration is the primary environmental variable that controls rates of degradation, especially of the more complex aromatic fractions of petroleum. Urban estuaries, such as Boston Harbor, can contain polycyclic aromatic hydrocarbons at up to 100 mg/gram of sediment. Once confined in aquatic sediments, the more complex fractions remain for indeterminate periods. Where long-term persistence of petroleum hydrocarbons has been documented, sublethal effects have been observed. Krebs and Burns (1977) studied populations of fiddler crabs (*Uca pugnax*) for 7 years after the West Falmouth spill of no. 2 fuel oil and observed long-term reductions in recruitment and population density, changes in sex ratios of adult crabs, behavioral changes, and increases in overwintering mortality. After the release of 8,000,000 liters of medium-weight crude oil from a ruptured oil-storage tank at the refinery on Isla Payardi in the Republic of Panama, Jackson et al. (1989) observed changes in stomatopod behavior and population structure, increased coral injury, and overgrowth by algae. Garrity and Levings (1990) observed reduced recruitment of snails at the same site for 2 years after the spill.

Salinity, temperature, mineral nutrients, oxygen availability, hydrocarbon concentration, biomass, acclimation of microbes to a particular hydrocarbon, and other factors can affect rates of hydrocarbon transformation (Bauer and Capone, 1988). Acclimation implies induction and growth of microorganismic enzyme systems capable of transforming hydrocarbons. The induction and growth depend on hydrocarbon concentration and the initial biomass of microorganisms present. Because petroleum is not a single defined organic compound, monitoring its biodegradation or transformation is complex and demanding. Indirect techniques (such as CO_2 evolution, O_2 consumption, and enzyme assays) can be used to estimate the overall fate of petroleum in water or sediments. With such methods, in situ hydrocarbon degradation rates in water have been estimated at 0.001-60 g/l per day (Bartha and Atlas, 1987).

Statistical Analyses

Environmental monitoring suffers conspicuously from the lack of adequate statistical test designs. A complete program of environmental monitoring should include support for development of statistical procedures appropriate to the specific problems being addressed. As in any scientific investigation, samples for environmental monitoring must be carefully constructed in combination with the statistical test that is contemplated to permit appropriate and effective testing of hypotheses (Carney, 1987). Testing of environmental impacts with monitoring data, however, poses special problems. First, many variables covary in natural systems, so separation of their influences is difficult or impossible. Second, appropriate "control" (untreated) sites might not exist, especially in tests of the effects of pervasive processes that could influence the benthos on large temporal or spatial scales. Third, replication of treated sites might be impossible, if there is only a single impact locality; this does not prevent rigorous testing of a potential impact at the site, but the site-specific nature of such tests renders extrapolation and generalization of the results risky or even impossible.

An example of the successful development of a rigorous test for site-specific impacts is the "BACI" test of Stewart-Oaten et al. (1986), which uses a creative solution of the general problem of achieving replication and identifying an appropriate control site. The test uses temporal replication before application of the environmental impact and provides temporally replicated estimates of the usual (pretreatment) differences between a control and an impact site. The pretreatment differences are then compared statistically against a time-series of differences after application of the impact.

A branch of applied statistics that needs further development to enhance environmental monitoring studies is power analysis. Power analysis is so rare in ecological studies that no universal standard has been established. Furthermore, the power of a test depends entirely on the size of the difference that one would like to be able to detect. Thus, in monitoring studies, it is important to determine the magnitude of impact that is deemed serious, so that power can be calculated against the appropriate alternative hypothesis. That is rarely if ever done. There is even merit in considering increasing the probability of rejecting a true null hypothesis, to increase power in environmental monitoring studies. All these issues require further analysis and development by experts in applied statistics.

Biological Hierarchy

Anthropogenic effects on benthic organisms can potentially be detected at a wide variety of organizational levels, ranging from molecular or cellular responses to ecosystem responses. It is prudent to conduct simultaneous tests for the influence of anthropogenic activities on the benthos at several levels of biological organization. Some tests at the cellular or physiological levels could prove to be more sensitive and better able to detect effects of anthropogenic influences, whereas changes at the population and community levels might more commonly reflect important consequences of those influences.

Most studies of marine benthic impacts have focused almost exclusively on detection of impacts without addressing their consequences. But the issue of consequences should be an important element of any program to study anthropogenic impacts on benthic populations of the continental shelf. Anthropogenic impacts can be measurable but of only trivial importance and of no consequence to maintenance of biological diversity, productivity of fish and shellfish stocks, remineralization of organic matter, or even population sizes and community structure of benthic communities. Presumably, such effects would be irrelevant to protection and preservation of benthic systems of the shelf.

Many indexes of sublethal stress have been proposed for monitoring the responses of organisms to anthropogenic impacts (McIntyre and Pearce, 1980), but few have been linked to the survival potential of individuals or the reproductive potential of a population. Particularly sensitive responses that might be related to population effects include biochemical and cellular responses that are associated with energy metabolism, membrane function, or detoxification and physiological responses that influence the energy available for growth and reproduction or for other aspects of reproductive and developmental processes (Capuzzo, 1987). Although sublethal responses have been demonstrated to be sensitive to anthropogenic influences (such as chronic petroleum discharges), it is difficult to ascertain the relationship between these responses and large-scale alterations in the functioning of marine ecosystems and the harvesting of fishery resources.

Because the spatial scales of larval dispersal of continental shelf benthos are so large and the natural mortality of larval marine benthic invertebrates is extremely high, population sizes might be largely decoupled from the reproductive output of spawning adults. The decoupling of population structure from the physiological condition of individual organisms makes it important to study local effects at both levels of biological organization. The best approach to assessing the effects of anthropogenic impacts on the marine benthos might involve an array of tests that include both studies of sublethal effects on individual organisms and measurement of changes at the population or community level.

Impairment of behavioral, developmental, and physiological processes could occur at concentrations much lower than acutely toxic concentrations and lead to alterations in the long-term survival of affected populations. Observed discrepancies between laboratory studies of acute toxicity and field assessments of the aftermath of major oil spills (Jackson et al., 1989) might be due at least in part to sublethal responses that alter the growth and reproductive potential of individuals in exposed populations.

Other Impacts

Overfishing of exploited finfish and shellfish stocks poses a qualitatively different anthropogenic impact on the benthic systems of the continental shelf. It is well established that the removal of top carnivores can have ramifications on biological interactions throughout an entire community. Bottom disturbance during trawling or dredging operations may have substantial effects on the benthic fauna, because such activities destroy the small-scale structure important for most infaunal species. It is important to note that collapse of populations due to overfishing and natural causes can be severe and sudden and can be independent of offshore hydrocarbon development. Given our current understanding of processes that control benthic community structure, separation of these impacts is difficult, if not impossible.

Summary of Monitoring Design Requirements

The need for broad-scale survey work has passed, and adequate general descriptions of the benthic environments of the U.S. continental shelf are in hand (Rabalais and Boesch, 1987). Future efforts must be directed toward designing sampling programs that define the magnitude of a perturbation that will have no detectable biological effect. The ESP has the ultimate responsibility to design monitoring approaches that incorporate statistical analyses of monitoring data, interpretation of results, coordination of ancillary monitoring and research efforts, and the publication of conclusions that have been subjected to appropriate and independent peer review. The ESP has the responsibility to assess not only the impacts of offshore exploration and development, but also the effects of transportation or other support activities on shoreline habitats.

An environmental monitoring program that will improve understanding of the impacts on benthic processes of OCS activities on the U.S. continental shelf must consider:

- Characterizing the spatial and temporal extent of impacts of discharges and disturbance, including the physical and chemical processes that regulate the fate and transport of contaminants from OCS activities.
- Measuring direct and indirect biological effects and distinguishing them from natural variation in ecosystem structure and function.
- Assessing the vulnerability of different shelf habitats and predicting recovery rates.
- Developing predictive models to assess the long-term effects of OCS activities.

As our knowledge of benthic systems increases, our ability to differentiate between anthropogenic impacts and natural variation should also increase. Given the present state of knowledge, however, our ability to predict impacts is minimal. Carney (1987) recommended that future studies focus on four major questions to resolve the differences between anthropogenic impacts and natural variation in benthic systems:

- Can impacts be related to processes that can be studied effectively in the field?
- If a faunal census approach is used, is something other than a species-by-species approach more informative and cost-effective?
- Can we substantially increase our understanding of the relationship between faunal and environmental spatial and temporal variation?
- What types of powerful and robust statistical models might be most applicable to long-term effects studies?

Until those questions are answered, studies might be limited to a faunal census approach, but at the very least such studies should follow good statistical design, should be aimed at hypothesis-testing, and should use both multivariate and univariate techniques. Recent efforts of the Intergovernmental Oceanographic Commission (IOC)/Group of Experts on the Effects of Pollutants (GEEP) Workshop on Biological Effects of Pollutants held in Oslo in 1986 demonstrated the robustness of multivariate and univariate techniques as applied to higher taxonomic units (i.e., family and higher) in resolving site-specific differences. The results suggest that more cost-effective approaches might be feasible in the analysis of anthropogenic impacts on macrofaunal communities and perhaps also on meiofaunal and microbial components (Bayne et al., 1988).

Preliminary surveys or reconnaissance can provide substantial information on a specific study site and provide the basis for the design of further long-term studies. Such a survey should include an analysis of the temporal and spatial patterns of faunal and environmental variables, including broad-scale characterizations of the biological, chemical, physical, and geological features of the region. Later studies should focus on defining the spatial and temporal distributions of impacts by time-series analysis of biological and other environmental features. That approach is now used in the assessment of the Santa Maria Basin and should serve as the model for future ESP benthic studies.

In the design of a sampling program for assessing the effects of offshore oil and gas operational discharges on benthic ecosystems, some effort should be used to determine the persistence and degradation rates of contaminants in sediments and the flux of these contaminants between sediments, interstitial waters, and biota. If the flux is substantial it is important to relate contaminant content in sediments, interstitial waters, and biota to changes in benthic biomass, the structure of benthic communities, recruitment success of benthic populations, and trophic interactions. Finally, demersal fish and shellfish populations that migrate little or not at all should be used as models to relate contaminant concentrations in biota to the activity of biotransformation mechanisms, reproductive condition, and incidence of energetic abnormalities and pathology.

As a means of addressing subtle chronic impacts, such a study design must integrate an understanding of the physics of bottom boundary layers, the chemistry of bioavailability of contaminants, and the biology of population structure and function, resource use, and recovery.

FISHERIES

MMS has sponsored many studies on fishery resources and some studies on the structure and function of ecosystems. However, the studies have provided relatively few quantitative assessments of the effects of OCS oil and gas activities on fishery resources, and assessments of the effects on ecosystems are almost completely lacking. The reason is not a lack of concern, but rather the complexity of the assessment problem. As noted in Chapter 2, efforts to understand the causes of population fluctuations in fisheries have met with limited success in all programs.

Information Needed

The most basic information that is needed is the spatial and temporal distribution of fishery resources and key ecosystem components. Life-history patterns should be understood well enough to permit one to identify critical habitat whose degradation could jeopardize a population. Spawning grounds, areas of concentration of eggs and larvae, nursery grounds, and migratory routes are particularly important.

Characterizing the distribution of fishery resources and other ecosystem components is needed for assessing the relative importance of habitat. In some cases, critical habitat is remote from drilling, but can be vulnerable to onshore OCS-related activity, e.g., pipeline routings through coastal wetlands, gravel islands and causeways in arctic regions, and channelization. One MMS study (Turner and Cahoon, 1988) examined the reasons for the loss of wetlands and the increasing rate of wetland loss in Louisiana. The study produced estimates of direct and indirect impacts on wetlands, quantified the extent of those impacts that resulted from OCS activity, and addressed some key questions regarding the mechanisms of those impacts. Critical coastal habitat can also be vulnerable to oil spills or blowouts. Quantitative assessment of the effects of OCS activity requires information on the fates of contaminant, i.e., spatial and temporal distribution of contaminants and their degradation products. Overlap in the distributions of contaminants and ecosystem components determines the magnitude of ecosystem exposure. Research on the biological effects of exposure (specified by concentration and duration) is an essential element for analysis.

Priority for studies of biological effects should be given to species that are potentially vulnerable (e.g., exposed to contaminants) and thought to be sensitive. Early life-history stages, such as eggs and larvae, are most likely to suffer lethal effects. The most important sublethal effects are the ones that can be related to demographic measures (e.g., reproductive output and growth rate) that govern the production and abundance of populations. Research might be necessary on the degree to which mobile organisms avoid and are likely to come into contact with oil and other material originating from OCS activity.

For fishery resources, traditional models of fishery population dynamics can be expanded to account for other sources of stress, such as those resulting from OCS activity (e.g., Schaaf et al., 1987). That approach takes advantage of the large literature on fish population dynamics and response to fishing.

Predicting the impacts of offshore oil and gas activities requires an understanding of the responses of marine biota to both chronic small discharges of drilling fluids, formation waters, and other contaminants from platforms and accidental discharges of larger volumes from blowouts or oil spills. Biological effects of contaminant discharges on marine biota depend on:

- Bioavailability and persistence.
- The ability of an organism to accumulate and metabolize contaminants.
- The interference of contaminants with normal metabolic processes so as to alter an organism's chances for survival and reproduction in the environment.

In considering the long-term effects of offshore oil and gas development activities, one should ascertain what biological effects might result in subtle ecological changes and impairment of fishery resources (Capuzzo, 1987). Rosenthal and Alderice (1976) concluded that the stages in the life cycle of marine fish (and most invertebrates) that are most sensitive to contaminant exposure are the development of gonadal tissue, early embryonic (pregastrulation) stages, the larval transition to exogenous food sources, and metamorphosis. Several investigators have shown that early embryonic and larval stages are more sensitive than later larval stages to petroleum hydrocarbons (see review in NRC, 1985; Capuzzo, 1987).

Sublethal effects of petroleum hydrocarbons on early life-history stages include a wide range of developmental and energetic abnormalities (Kuhnhold, 1974; Linden, 1976; Smith and Cameron, 1979; Linden et al., 1980; Hawkes and Stehr, 1982; Capuzzo et al., 1984). Cod and pollack eggs collected after the *Argo Merchant* oil spill had a high incidence of cytological deterioration and abnormal differentiation (Longwell, 1977). Effects of petroleum hydrocarbons on reproductive and developmental processes include interference with hormone synthesis (Truscott et al., 1983), impairment of gonad development (McCain et al., 1978), transfer of hydrocarbons from gonads to early developmental stages (Koster and Van den Beggelaar, 1980), and reduced hatching success (Kuhnhold, 1978; Sharp et al., 1979). Sharp et al. (1979) suggested that hydrocarbon exposure of embryonic and larval stages might result in the shunting of energy reserves away from critical differentiation and morphogenic processes to metabolic maintenance.

Sublethal changes in energetics of adult organisms as a result of petroleum exposure can increase susceptibility to other environmental stresses, such as disease. Several studies have shown a direct correlation between hydrocarbon stress and increased incidence of histopathological conditions (McCain et al., 1978; Sindermann, 1982; Murchelano and Wolke, 1985). Populations of plaice (*Pleuronectesplatessa*) collected from oil-contaminated estuaries after a spill from the *Amoco Cadiz* had reduced growth rates and fecundity (Conan, 1982) and histopathological aberrations (Haensly et al., 1982; Stott et al., 1983). As illustrated in Figure 3-1, impairment of energetic and developmental processes occurs at much lower than acutely toxic concentrations.

Polycyclic aromatic hydrocarbons and other lipid-soluble foreign compounds are metabolized by many marine vertebrates and invertebrates (Bend and James, 1978; Stegeman, 1981). Metabolism affects the disposition or increases the removal of the compounds; it can also transform them to potentially more toxic derivatives. Malins (1982) suggested that metabolic transformation could be linked to a wide range of cytological, structural, and developmental abnormalities.

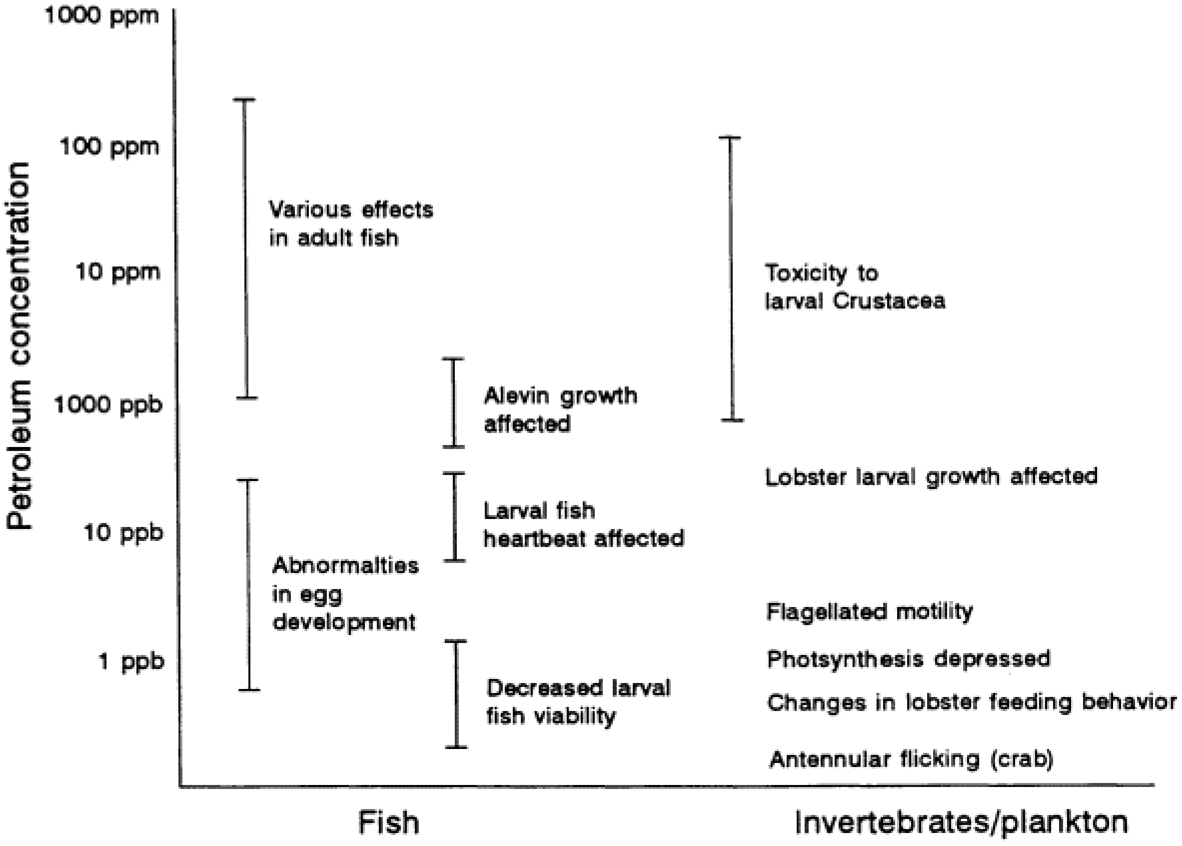


Figure 3-1
Comparison of lethal and sublethal effects of petroleum hydrocarbons on fish and invertebrates.
Source: Vandermeullen and Capuzzo, 1983.

Long-term effects of offshore oil and gas development can be both direct (through the loss of reproductive or recruitment success) and indirect (through the disruption in food-chain dynamics). Both types of impacts are difficult to assess, because of our lack of knowledge of natural variability in reproductive effort and recruitment and of flexibility in prey selection by commercially important species of fish and shellfish. Although MMS has used oil-spill models to predict the spatial and temporal interactions of spills with eggs and larvae, little attention has been given to predicting the impact of chronic exposure on reproductive or developmental success.

MMS, through the NOAA/OCSEAP, supported numerous studies relevant to the fishery resources of the Alaska OCS, including toxicity studies related to early life-history stages of Alaska fish and invertebrate species (Rice et al, 1983); studies of sublethal effects of petroleum hydrocarbons on salmonids, king crab, and other species (Rice et al., 1983); studies of effects of hydrocarbons on cytological, cytogenetic, and histopathological disorders (e.g., McCain et al., 1978; Hawkes, 1980; Malins et al., 1982; Varanasi and Gmur, 1981); and studies of habitat and distribution of commercially important species (Rice et al., 1983). In addition, fishery models have been developed to assess the impact of OCS activities; these are discussed in the modeling section.

Those studies have provided a fundamental understanding of the broad range of responses of fishery species to petroleum hydrocarbons. Techniques developed in them are suitable for application in monitoring the effects of OCS activities, especially the short-term effects of produced waters and the long-term effects of accidental petroleum discharges. Similar studies were conducted during the evaluation of the effects of the *Exxon Valdez* oil spill, but the results were not available to the panel for review. A recent workshop on fisheries oceanography in the Arctic (Meyer and Johnson, 1990) identified specific research needed for assessing fishery resources at risk from oil and gas activities in the Arctic, primarily in the Beaufort and Chukchi seas. Characteristics related to the distribution, habitat requirements, and reproductive biology of important species were identified as information gaps, especially during the winter months when habitats are covered by ice.

ECOSYSTEM MODELING

Mathematical models should play an important role in assessing the effects of OCS activity, although they must be used with caution. Models of the fates of contaminants—which require focused studies of physical and geochemical processes—should be developed to assess ecosystem effects of OCS activity. Models have been used to study the fates of contaminants from acute events, such as blowouts and oil spills.

Biological Models Developed with MMS Funding

Circulation Models

Although this section is concerned primarily with fishery and ecosystem models, a brief discussion of circulation models is warranted, because the physical environment is the primary determinant of contaminant distribution. MMS has funded the development of several circulation models that range from regional-circulation models (e.g., of the West Florida Shelf) up to basin-scale models (e.g., the Gulf of Mexico). The models have been reviewed by the

Physical Oceanography Panel, whose report (NRC, 1990a) should be consulted for details and evaluations of the models.

The current distributions obtained with the circulation models are used in two ways. First, the simulated current distributions are used in conjunction with the Oil Spill Risk Assessment model to determine statistically the direction of transport of oil discharged into the marine environment and the probability that spilled oil will reach specified "targets" (usually segments of shoreline). The trajectories produced by the model can be used to assess the risk to a particular population (e.g., sea otters or birds), if the distribution and population dynamics of the population are known. Second, the simulated current distributions can be used directly in a coupled physical-biological model as variable coefficients to provide the physical forcing that transports constituents (e.g., biological constituents or contaminants) throughout a given region. Given the importance of currents in determining the distribution of constituents in the marine environment, the assumptions and procedures used to develop the circulation model must be carefully considered before the output of one of these models is used to assess biological questions. In particular, circulation models typically are formulated to represent space and time scales that are larger than the scales that are important in biological oceanographic and fishery problems.

Population Risk Models

MMS has supported attempts to construct models to investigate the effect of oil spills on organisms, such as marine birds and mammals. Reed et al. (1986) constructed a model to consider the effects of oil spills in the Bering Sea on the population dynamics of northern fur seals in different seasons. The available data were derived from observations of fur seal migration routes and various population measures, such as reproductive and mortality rates. The primary benefit of the study was in pointing to the need for additional data, if such modeling efforts were to be predictive for natural populations.

The study of Siniff and Ralls (1988), also described earlier in this chapter, helped to predict the effects on the sea otter population of an oil spill along the California coast. Although the study was valuable in helping to predict recovery times for a population of sea otters after oil spills of different magnitudes and in different regions of the California coast, and it also demonstrated the need for additional information data on various population measures.

Ford et al. (1982) used a modeling approach to consider the sensitivity of colony-breeding marine birds to oil spills within the birds' foraging area. Their model consisted of submodels for bird population demographics and foraging behavior. Sensitivity analyses of the population characteristics included in the submodels revealed that the model results were sensitive to values chosen for some of them. The study concluded that the realism of the modeling analysis was hampered by the lack of field observations that would make it possible to specify several of the critical model elements, a conclusion applicable to many modeling studies.

Ecosystem and Oil-Flux Models

As a result of MMS and MMS-related activities, mathematical models have been developed to investigate the biological impact of oil spills and to synthesize and integrate multidisciplinary data. One example is the BIOS (Biological Impact of an Oil Spill) ecosystem simulation model, developed by OCSEAP as part of its eastern Bering Sea environmental impact study. It is a multicomponent model in which most parts of the marine ecosystem and the effects of pollution on organisms, such as fish, are represented in some fashion. The model was used primarily to estimate contaminant concentrations in some fish species and some benthic organisms that result from exposure to oil-contaminated water and sediments and the consumption of oil-contaminated food. Decontamination processes are also included in the calculation of oil-contaminant concentrations in a particular organism. In general, water-column processes (e.g., phytoplankton and zooplankton influences) are included only to the extent they provide food sources for the benthos for the transfer of oil to the sea floor. The model allows for spatial variability due to fish migration and provides an estimate of the amount of contaminated biomass that leaves the model region. The BIOS model and simulations performed with it are described in several technical reports (e.g., Gallagher, 1984; Gallagher and Pola, 1984; Swan, 1984).

Although not funded by MMS, a complex ecosystem model was constructed for the Buccaneer Field study off the Louisiana coast (Fucik and Show, 1981). The model was supported by EPA and NOAA and was developed to aid in evaluating the effects of offshore oil and gas production on the marine environment. Like the BIOS model, the Buccaneer Field model is a multicomponent model. It consists of a system of coupled ordinary differential equations that describe the time-dependent behavior of several biological components and several chemical constituents. Each biological or chemical component is divided into several processes, each of which can be affected by processes in other compartments. The time-dependent model itself is coupled to a hydrodynamic model to obtain spatial distributions.

The biological portion of the Buccaneer Field model consists of 10 components that describe the trophic dynamic relationships in the region of interest. The hydrocarbon portion comprises four chemical constituents—aliphatics, aromatics, branched and cyclic alkanes, and alkyl-substituted aromatics—that are divided on the basis of molecular weight and are acted on by six weathering processes.

The Buccaneer Field model was used to investigate seasonal biomass trends and to describe the flow and storage of carbon between the various biological components. The chemical portion was used to estimate the percentage of total hydrocarbons lost because of weathering. Finally, the combined model was used to obtain average steady-state hydrocarbon concentrations in each biological compartment. Model results implied that the major flow of material in the Buccaneer Field system was through phytoplankton. The short residence time of phytoplankton in the Buccaneer Field region (due to advection), however, indicates that there is only a small probability that contaminated phytoplankton are being preyed on by other organisms in the Buccaneer Field. Nevertheless, contaminated particles might be transported to other locations and incorporated into the food webs there.

Fishery Models

MMS has sponsored the development of two fishery models to assess the effects of OCS activity quantitatively: the Georges Bank model (developed by Spaulding, et al., 1982) and the Bering Sea model (developed by Laevastu et al., 1985). MMS recently commissioned critical reviews of those models by Fletcher (1989) and Deriso (1989). The panel in general agrees with those reviews, whose major points are included in this section.

The Georges Bank model was designed to assess the effects of an oil spill on fishery resources of Georges Bank. It considers only the direct effect of oil on pelagic early life-history stages. It is composed of four submodels: a hydrodynamic model, an oil-spill fate model an ichthyoplankton transport and fate model, and a fish-population model. The first two submodels have been reviewed earlier (NRC, 1990a). The Georges Bank model is applied to four traditionally important fish species: cod, haddock, sea herring, and yellowtail flounder.

The ichthyoplankton transport and fate model treats pelagic eggs and larvae as passive drifters, subject to local horizontal currents averaged over the top 10 m of the water column. The currents are derived from the hydrodynamic model. The vertical distribution of ichthyoplankton, however, is known to be variable and frequently is often related to such physical features as thermoclines (e.g., Buckley and Lough, 1987). Ichthyoplankton might not be passive with respect to vertically averaged current fields; some species are known to have persistent concentrations in areas where average horizontal currents are strong (e.g., Georges Bank herring, Iles and Sinclair, 1982). The spatial and temporal distribution of the pelagic ichthyoplankton of Georges Bank has been sampled extensively by NMFS. Where the data are available, one can use empirical distributions of ichthyoplankton in oil-spill assessment models, instead of modeling ichthyoplankton transport. Where data are lacking, data on distribution should be collected to verify ichthyoplankton transport models. Where spawning has a wide temporal and spatial distribution (e.g., Georges Bank cod), verification will be difficult.

The Georges Bank fish population submodel assumes a compensatory spawner-recruit function, although no empirical data support this assumption for cod. If the assumption is invalid, the impact of an oil spill will be underestimated. Because the commercially exploited fishery resources of Georges Bank have been depleted by overfishing (NMFS, 1988b), they might not be able to compensate for the additional stress of an oil spill. The maximal effect of an oil spill should have been assessed without the assumption of spawner-recruit function.

The Bering Sea model is more ambitious (not necessarily more useful) than the Georges Bank model. It considers the effect of oil that settles to the bottom on demersal eggs and larvae of Pacific cod and red king crab, in addition to the effects of surface oil on pelagic eggs and larvae of yellowfin sole and walleye pollack. It also models the tainting of juvenile and adult king crab, sockeye salmon, and 16 other fish species. The Bering Sea model is poorly documented, so it is difficult to evaluate. Many parameter values are drawn from unpublished sources that are not readily accessible. The initial conditions for juvenile and adult fish biomass are taken from an ecosystem model, "Dynumes" (Laevastu et al., 1985), which is also poorly documented and unverified.

The Bering Sea model shares the two shortcomings of the Georges Bank model. It assumes passive drift of eggs and larvae according to vertically averaged horizontal currents; empirical data on the spatial and temporal distribution of eggs and larvae in this region are inadequate for use in impact assessment or model verification. For most simulations performed with the Bering Sea model, recruitment is assumed to be independent of spawners (having no functional relationship with them); this is equivalent to assuming strong compensation, which can result in an underestimate of the impact of an oil spill. A noncompensatory spawner-recruit relationship is used in a sensitivity analysis, but it is not used as the basis of the primary conclusions from the Bering Sea model.

Drilling Discharges

The Offshore Operators Committee (OOC) and Exxon Production Research Company developed a computer model to simulate the short-term fate of drilling mud discharged into most areas under a variety of environmental and discharge conditions. The model has its origins in the U.S. Army Corps of Engineers-Environmental Protection Agency Dredge Spoil

Model. It is used to predict the average concentrations of solids and soluble components in the discharged material in the region surrounding the discharge site and the concentration of the solids initially deposited on the sea floor. The OOC mud-discharge model was distributed to OOC member companies and federal and state agencies concerned with offshore-drilling discharge regulation in September 1983 (O'Reilly et al., 1989). The model has been used extensively in predicting the impact of discharged material on the marine environment.

The mud-discharge model assumes that drilling-mud discharges originate as a jet from a submerged pipe at an arbitrary orientation. The behavior of the discharged material after release is assumed to be characteristic of one of three phases: convective descent of the jet of material; dynamic collapse, which occurs when the descending plume either hits the bottom or arrives at a level of neutral buoyancy, when descent is retarded and horizontal spreading dominates; and long-term passive diffusion, which begins when transport and spreading of the plume is determined more by ambient currents and turbulence than by any dynamic character of its own (Brandsma et al., 1980). Each phase can be represented mathematically, given an appropriate set of assumptions.

The equations that describe the first phase of the discharge, a negatively buoyant plume, are for conservation of mass, momentum, buoyancy, and solids. The conservation equations are in terms of distance along the plume. The mud-discharge model allows for up to 12 discrete classes of particles and a fluid fraction. Each particle class is described by the particle concentration, particle density, and particle settling velocity. The jet itself is described by its radius, its velocity along the jet axis, and its density. The second phase, dynamic collapse, is governed by the same conservation equations, but with the addition of an equation to describe the collapse of the elliptical cross section that is assumed to characterize the plume. In the final phase, the plume has become dynamically passive and is acted on by turbulent diffusion, advection, and settling of the solid particles. The long-term diffusion of the plume in this phase is handled with a LaGrangian scheme of diffusion. Detailed descriptions of the mud-discharge model are given by Brandsma et al. (1980) and Brandsma and Sauer (1983).

The mud-discharge model was verified and calibrated with field studies of discharges into the environment. The most extensive was conducted from a production platform off California in January 1984. In general, the observed and predicted distributions of the particles originating from the discharge agreed. The field study and comparisons between the model and observed distributions are described by O'Reilly et al. (1989).

The OOC mud-discharge model appears to be adequate for determining the average concentration of solids and particles immediately after discharge into the environment. It is not sufficient for determining the longer-term distribution of discharged material; it was not designed to provide more than short-term near-field distributions.

Evaluation of MMS Modeling Efforts

Aside from a major expenditure of resources to develop a fishery model, MMS has made few attempts to use models to consider oil and hydrocarbon effects on marine organisms. In general, the models that have been developed for the latter purpose consist of systems of coupled ordinary differential equations that consider the time-dependent effects of oil contaminants on various organisms. The parameterization of biological processes is based on empirical formulations; in some cases, the "educated guess" approach is used for unknown quantities that are difficult or impossible to estimate. That is not uncommon in biological models; however, the MMS models, such as the BIOS model, have a preponderance of coefficients that are so determined. Consequently, conclusions or predictions derived from the models have little value. In some instances, the biological models have been coupled to hydrodynamic models to obtain spatial distributions. Again, the validity of the circulation model must be considered when assessing the reliability of the model predictions.

MMS has used the models it has developed in two ways: to assess acute short-term effects and to assess chronic long-term effects. Acute effects can be addressed with the oil-spill trajectory models that have been developed for various regions. Those models give the statistical probability related to where the impact of an oil spill will be greatest. That information, when used in conjunction with models of bird or seal distributions, can be useful for short-term management decisions. The effectiveness of the approach is determined by the adequacy of the oil-spill model and the availability of good biological distribution data and measurements of population growth and mortality. The models presented by Ford et al. (1982) and Reed et al. (1987) are examples. As indicated in each of the models, however, values of critical population parameters are not available. In addition, the circulation models on which the population risk models depend are of questionable accuracy (NRC, 1990a).

The assessment of chronic effects entails a different modeling approach. Models that treat couplings between ecosystem components are required, but measurements of the trophic couplings need to be available first. As discussed earlier, MMS has attempted to develop this type of model. The existing models, such as BIOS and Buccaneer Field Study, are complex, cumbersome, and dependent on little known or completely unknown coefficients. The type of data needed to verify their output is lacking. This field needs improvement, especially if MMS desires to focus on long-term effects of OCS activities.

4

Conclusions and Recommendations

CONCLUSIONS

The Minerals Management Service's mandate to assess potential impacts of OCS activities, as specified in the OCS Lands Act as amended in 1978 and in other authorities, although reasonable from the viewpoint of public policy, required the acquisition of information and the development of predictions that could not be accomplished with the available time, resources, and scientific expertise. Therefore, MMS has allocated its resources to studies that support specific lease sales at the expense of longer-term studies that would have provided a better scientific basis for prediction and assessment of impacts of OCS activities.

In general, with a few exceptions, the panel found that the information available on inventories and distribution of marine birds and mammals and the characterization of benthic environments were adequate to define the resources at risk because of OCS activities. The principal exception to that finding is the lack of information collected for OCS areas in the Gulf of Mexico, specifically on the at-sea distribution of birds and mammals; the distribution and abundance of sea turtles; and characterization of benthic communities, especially in deeper waters. In addition, data on seasonal and interannual variation of many ecological aspects of OCS areas are lacking.

There have been insufficient process-oriented programs for many regions of the OCS, studies that would yield information on ecological processes, population dynamics of resource species, and interactions between physical and chemical processes and biological communities. Such information is needed to support assessments of the sensitivity and vulnerability of biological communities to OCS-related activities, and it will also provide a basis for developing strategies for reducing impacts and mitigating them. Studies linking an understanding of physical and chemical processes, of their effects on biological communities, and of the fate and transport of OCS-related discharges are critical during all phases of OCS oil and gas activities. Those studies should assess not only the short-term effects of exploratory drilling on the OCS, but the long-term effects of chronic discharges during exploration, development, and production. The latter point was recommended in an earlier review of the OCS oil and gas program (NRC, 1978). The studies should also address potential cumulative effects on migratory species (e.g., gray and bowhead whales) that occur seasonally in different OCS regions.

There has been insufficient focus in the ESP on impacts of OCS activities on nearshore and onshore communities that, although unlikely to be affected during the early stages of exploration, could be seriously affected when shore-based facilities are constructed or spilled oil moves ashore. Concern for nearshore and onshore communities was highlighted in earlier studies (NRC, 1978, 1989a), especially regarding areas where critical habitats of endangered or threatened species could be affected (e.g., the Gulf of Mexico).

Impact analyses to date have been narrowly focused on the potential impacts of spilled oil. More attention needs to be given to the other potential impacts of OCS development and production, including those associated with the combined discharge of drilling fluids, produced waters, spill dispersants, and other chronic discharges, in addition to ship and aircraft traffic, onshore development, pipeline construction, and removal of facilities as well as the overall cumulative effects of significant industrialization related to OCS oil and gas activities in an area and how impacts could be reduced.

Regional programs within the ESP vary from one region to another in the scientific quality of completed studies, the integration of data from different disciplines, and the acquisition of critical information. The variation was also recognized by the OCS Physical Oceanography Panel in its review of the ESP (NRC, 1990a). MMS should develop stronger scientific bases for its strategies for the acquisition of ecological information that can be incorporated into regional study plans. Strengthening the scientific bases of its strategies would result in less-fragmented studies that are better integrated across disciplines and regions and more closely fulfill the mandate for assessing the impacts of OCS oil and gas activities. Using the criteria highlighted in this report (Chapter 1) and a sound scientific strategy, priorities for regional study plans may be developed with an understanding of both the resources and habitats at risk and their vulnerability to various activities throughout the full range of OCS oil and gas activities (i.e., exploration through decommissioning).

Although some extensive data sets have been acquired (especially resource inventories), MMS has not yet established a data management system that will always allow it to determine where its effort has been expended or where biological resources are. The panel understands that MMS is again working on the development of a computerized data management system that is intended to permit retrieval of data on study effort, as well as on the distribution and abundance of organisms.

RECOMMENDATIONS

The panel offers six general recommendations for future ESP ecological studies.

- **The ESP should support more ecological process-oriented studies and studies of ecological relationships designed to predict environmental impacts of OCS oil and gas activities.**

A major achievement of the ESP was the characterization of benthic habitats and the distribution of bird and marine mammal populations. Although identification of resources at risk and characterization of habitats will still be required in new frontier areas of the OCS, the need for only broad-scale survey work has passed. Future research should focus on process-oriented programs designed to evaluate mechanisms that control the distribution of populations and communities such as trophic links between benthic habitats and pelagic communities. The research should focus on the appropriate temporal and spatial scales. For example, the processes by which and the rates at which populations recover from disturbance must be understood in all habitats affected by OCS-related activities. In addition, there is a critical lack of understanding of the proper temporal and spatial scales for evaluating OCS-related impacts, especially on benthic areas. Existing data (data from MMS, data on fisheries, and any other available data) should be analyzed and used to discern proper scales for future research. It is critical to use information gained from studying OCS impacts and attempts to mitigate them in planning future activities. In other words, OCS activities should be treated as scientific experiments whenever possible.

MMS, through the National Oceanic and Atmospheric Administration's Outer Continental Shelf Environmental Assessment Program (NOAA/OCSEAP), supported the development of analytical chemical techniques for determining concentrations of hydrocarbons and biochemical techniques for examining sublethal effects of hydrocarbon contaminants, metabolites, and reaction products. Advances in methodology have progressed in the scientific community at large with funding from various sources. These techniques have improved understanding of the fate and effects of hydrocarbon contaminants in the marine environment. MMS should incorporate them into future study plans to improve understanding of the biogeochemistry of hydrocarbons that might affect benthic ecosystems.

The vulnerability of different shelf habitats to discharges from OCS oil and gas activities and the mechanisms that control recovery are not well understood. MMS should continue to direct its efforts toward a greater understanding of the mechanisms involved in habitat restoration and recovery.

For birds, MMS should promote studies of processes responsible for foraging aggregations, both near and away from breeding colonies, and integrate them with work in other specific disciplines (physical and biological oceanography, fisheries, etc.). MMS should cooperate with other organizations to take advantage of and help support current long-term studies of reproductive ecology that are developing data on population and community processes. MMS should conduct additional surveys of migratory routes to identify areas of concentration and their timing. For marine mammals, MMS should ensure that the emphasis of studies on high-profile species is not at the expense of others, less visible, that may be more sensitive or vulnerable.

OCS oil and gas activities constitute only a portion of all human activities in the coastal and continental shelf areas (e.g., commercial fishing, shipping, sewage discharge, etc.) that can have adverse impacts on ecosystems and living resources. Thus, an understanding of the interactions of OCS activities and other disturbances is needed for an assessment of absolute and relative environmental impacts of OCS oil and gas activities.

In addition, OCS oil and gas development could have serious immediate and chronic long-term effects on intertidal and nearshore habitats. Because of their popular appeal and exposure to waterborne oil and debris, the narrow intertidal habitats are among the most valuable, yet vulnerable, marine habitats in the world. Although these fragile habitats and ecosystems are inshore of the legal OCS limits, they are vulnerable to the effects of OCS oil exploration and development and must be better represented in MMS's studies.

- **More emphasis is needed on long-term and postlease studies that are directed toward a better understanding of the environmental impacts of OCS development and production.**

Until recently, ESP studies have focused on preleasing activities, primarily in frontier regions of the OCS, and not on the effects of exploration, development, and production. Almost all the natural patterns represent time scales that must be evaluated in terms of decades, rather than years; and it is absolutely critical that long-term (multiyear) postlease studies be established. Postlease research involving exploration, development, and production must include long-term programs that can discriminate between natural changes and OCS-related changes and can discern interactions of OCS activities with other human activities in specific regions. Long-term studies, including time-series analysis (such as those conducted in the California

Cooperative Fisheries Investigation), should define the spatial and temporal extent of the impacts of OCS activities. For birds, MMS should establish a subset of potentially vulnerable colonies and should run a statistically based program to monitor numbers and reproductive biology of selected species during leasing, exploration, and production. Detailed long-term monitoring studies should also be done for selected species of marine mammals. The development of monitoring programs to verify predicted effects can be used to ensure that effects do not reach unacceptable levels. MMS should hold a workshop and collaborate with other agencies (e.g., FWS, NMFS, state agencies) to identify useful indicator species and to outline the types of long-term monitoring studies that could be done to verify the predicted effects, and detect the possible unforeseen effects of OCS activities in different regions.

One important component of postlease analysis is the understanding of the long-term effects of oil spills on both the OCS and nearshore habitats. Therefore, MMS should take advantage of accidental and experimental oil spills for research, to examine the persistence of hydrocarbons in the marine environment, to identify the processes related to the degradation of hydrocarbons, and to define the mechanisms that control the recovery of specific biological communities (as it did in a recent study of the *Nestucca* oil spill off the Washington coast (Strand et al., 1990)). It is extremely important that the sites of large oil spills receive periodic restudy. MMS should hold a workshop, together with other agencies, to develop contingency plans for responding scientifically to different kinds of oil spills in different areas and to use them as a means for verifying otherwise unverifiable hypotheses concerning the effects of oil and marine living resources and the ecosystems of which they are a part. The data collected from many studies of the *Exxon Valdez* oil spill were not available for review and incorporation into this report. When most of the data have been made public and peer-reviewed, we are likely to gain valuable insights about the fate and effects of spilled oil in subarctic environments.

• Models are important for understanding ecosystem processes and environmental impacts of OCS activities. However, the development of models requires observational data for verification, and use of models does not replace the need for further work in the assessment of environmental impacts of OCS activities.

Modeling is an important tool that can provide insights into a variety of ecosystem processes and should be used not as a substitute for field programs, but in conjunction with field programs to identify specific information gaps. To improve predictive capability for ecosystem modeling, MMS should:

—Use models to identify critical data gaps and processes that must be understood to predict accurately the possible environmental impacts of OCS activities.
—Provide data on rates and processes for models.
—Take advantage of theory and techniques that are being developed for constructing ecosystem models.
—Take advantage of modeling expertise that exists outside of current MMS contractors.

In all cases, models should be tested against and calibrated with field observations before their outputs are used to assess and manage OCS environmental impact.

• MMS needs a data management system that is accessible in a timely manner and allows the integration of information from different disciplines.

MMS has produced a large quantity of data—some interpreted, some not. Improvement is needed in MMS's data management, including synthesis, storage, and retrieval. MMS should continue to develop integrated data bases on biological resources potentially at risk. The data bases should be reproducible as maps. Formats should permit ready retrieval on a geographic basis. GIS systems could be developed and used to help organize and integrate multidisciplinary geographic data in each OCS region. MMS should continue to develop information exchanges with other agencies. In addition, MMS should continue to encourage the publication of study results in the peer-reviewed scientific literature. Final reports can be difficult to find, and they often are not critically reviewed or integrated for an understanding of broad-scale impacts of OCS-related activities when not published in peer-reviewed scientific literature.

- **MMS should sharpen its focus on the specific scientific hypotheses underlying its strategies for the acquisition of information so that the information can be incorporated into regional study plans, and should strive to integrate regional study plans across disciplines and regions.**

MMS needs to develop study plans that include more hypothesis-testing and greater recognition of the spatial and temporal scales on which effects of specific OCS activities can occur. The recommendations of Carney (1987) for the design of benthic monitoring programs can be applied to other aspects of the OCS program, specifically in the selection of processes that can be studied, statistical design of sampling programs, and identification of appropriate temporal and spatial scales for sampling specific characteristics.

- **MMS should help in the curatorship of the large collections obtained during its studies.**

MMS requires (appropriately) that samples be competently identified and that voucher specimens be maintained. It is critical for determining whether change has occurred that all specimens be available for inspection. Indeed, frozen tissue samples from selected animals also offer extremely important reference information for assessment of future impacts of OCS activities. In order to provide taxonomic continuity for future MMS-supported research, MMS should support the systematists that made the benthic programs possible, and especially should support the extremely important long-term curatorship of archived samples. The marine mammal tissue bank being developed by NMFS (to which MMS contributes) could usefully be expanded to include birds and fish.

References

Ainley, D.G., and R.J. Boekelheide. 1990. Seabirds of the Farallon Islands: Ecology and Dynamics of an Upwelling-System Community. Stanford: Stanford University Press. 445 pp .

Ainley, D.G., C.R. Grau, T.W. Roudybush, S.H. Murrell, and J.M. Utts. 1981. Petroleum ingestion reduces reproduction in Cassin's Auklets. Mar. Pollut. Bull. 12:314-317 .

Amstrup, S.C., I. Stirling, and J.W. Lentfer. 1986. Past and present status of polar bears in Alaska. Wildl. Soc. Bull. 14:241-254 .

Amstrup, S.C., C. Gardner, KC. Myers, and F.W. Oehme. 1989. Ethylene glycol (antifreeze) poisoning in a free-ranging polar bear. Vet. Hum. Toxicol. 31:317-319 .

Armstrong, H.W., K. Fucik, J.W. Anderson, and J.M. Neff. 1979. Effects of oilfield brine effluent on sediments and benthic organisms in Trinity Bay, Texas. Mar. Environ. Res. 2:55-69 .

Arneson, P.D. 1980. Identification, documentation and delineation of coastal migration bird habitat in Alaska. Environmental Assessment of the Alaskan Continental Shelf, Final Reports of Principal Investigators. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Juneau, Alaska. Biol. Stud. 15:1-363 .

ASA (Acoustical Society of America). 1981. San Diego Workshop on the Interaction Between Man-made Noise and Vibration and Arctic Marine Wildlife. Report to the Alaska Eskimo Whaling Committee, Barrow, Alaska, Acoustical Society of America, Washington, D.C.

Atlas, R.M., P.D. Boehm, and J.A. Calder. 1981. Chemical and biological weathering of oil from the *Amoco Cadiz* spillage within the littoral zone. Estuar. Coastal Shelf Sci. 12:589-1608 .

Aurand, D.V. 1988. The future of the Department of the Interior OCS Studies Program. Paper presented at "Oceans '88" Conference sponsored by Marine Technology Society, IEEE, October 31-Nov. 2, Baltimore, Md.

Balcom, B.J. 1981. Results of the 1976-78 Baseline Studies and Analysis Program: Subtidal Benthic Environments of the Southern California Bight. Technical Report No. 81-8. U.S. Department of the Interior, Bureau of Land Management, Pacific OCS Office, Los Angeles, Calif., 73 pp .

Barnard, J.L. 1963. Relationship of benthic Amphipoda to invertebrate communities of inshore sublittoral sands of southern California. Pac. Natur. 3:439-466 .

Barnard, J.L., and O. Hartman. 1959. The sea bottom off Santa Barbara, California: Biomass and community structure. Pac. Natur. 1:1-16 .

Bartha, R., and R.M. Atlas. 1987. Transport and transformations of petroleum: Biological processes. Pp. 287-341 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Bartonek, J.C., and D.N. Nettleship. 1979. Conservation of marine birds of northern North America. U.S. Department of the Interior, Fish and Wildlife Service, Wildlife Research Report 11.

Battelle/WHOI (Woods Hole Oceanographic Institution). 1983. Georges Bank Benthic Infauna Monitoring Program. Final Report, Year 1. Contract No. 14-12-001-29192. U.S. Department of the Interior, Minerals Management Service, New York OCS Office, New York. 153 pp .

Battelle/WHOI (Woods Hole Oceanographic Institution). 1984. Georges Bank Benthic Infauna Monitoring Program. Final Report, Year 2. Contract No. 14-12-001-29192. U.S. Department of the Interior, Minerals Management Service, Atlantic OCS Office, Vienna, Virginia. 173 pp .

Bauer, J.E. and D.G. Capone. 1988. Effects of co-occurring aromatic hydrocarbons on degradation of individual polycyclic aromatic hydrocarbons in marine sediment slurries . Appl. Environ. Microbiol. 54:1644-1655 .

Bayne, B.L., R.F. Addison, J.M. Capuzzo, K.R. Clarke, J.S. Gray, M.N. Moore, and R.M. Warwick. 1988. An overview of the GEEP Workshop. Mar. Ecol. Prog. Ser. 46:235-243 .

Bean, M.J. 1983. The Evolution of National Wildlife Law. New York: Praeger Publishers.

Bedinger, C.A., Jr., ed. 1981. Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico. Final Report to U.S. Department of the Interior, Bureau of Land Management, Contract No. AA551-CT8-17, Southwest Research Institute, San Antonio, Tex.

Bend, J.R., and M.O. James. 1978. Xenobiotic metabolism in marine and freshwater species. Pp. 128-188 in Biochemical and Biophysical Perspectives in Marine Biology, Vol. 4 ., D.C. Malins and J.R. Sargent, eds. New York: Academic Press.

Berthou, F., G. Balouët, G. Bodennec, and M. Marchand. 1987. The occurrence of hydrocarbons and histopathological abnormalities in oysters for seven years following the wreck of *the Amoco Cadiz* in Brittany (France). Mar. Environ. Res. 23:103-133 .

Bilyard, G.R., and A.G. Carey, Jr. 1979. Distribution of western Beaufort Sea polychaetous annelids. Mar. Biol. 54:329-339 .

Bilyard, G.R., and A.G. Carey, Jr. 1980. Zoogeography of western Beaufort Sea Polychaeta (Annelida). Sarsia 65:19-26 .

Bjorndal, K.A., ed. 1981. Biology and Conservation of Sea Turtles. Proceedings of the World Conference on Sea Turtles, 26-30 November, 1979. Washington, D.C.: Smithsonian Institution Press. 583 pp .

BLM (Bureau of Land Management). 1978. Study Design for Resource Management Decisions: OCS Oil and Gas Development and the Environment. U.S. GPO Order No. 1979 0-287-656. U.S. Department of the Interior, Bureau of Land Management, Washington, D.C.

Blumer, M., R.R.L. Guillard, and T. Chase. 1971. Hydrocarbons of marine phytoplankton. Mar. Biol. 8:183-189 .

Boehm, P.D. 1983. Long-term fate of crude oil in the Arctic nearshore environment: The BIOS experiments. Pp. 280-291 in Proceedings of the Sixth Arctic Marine Oil Spill Program Technical Seminar. Environmental Protection Service, Ottawa, Canada.

Boehm, P.D. 1987. Transport and transformation processes regarding hydrocarbon and metal pollutants in offshore sedimentary environments. Pp. 233-286 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Boehm, P.D., and J.W. Farrington. 1984. Aspects of the polycyclic aromatic hydrocarbon geochemistry of recent sediments in the Georges Bank region. Environ. Sci. Technol. 18:840-845 .

Boehm, P.D., D.L. Feist, and A. Elskus. 1981. Comparative weathering patterns of hydrocarbons from the *Amoco Cadiz* oil spill observed at a variety of coastal environments. Pp. 159-173 in Proceedings of International Symposium on the *Amoco Cadiz:* Fates and Effects of the Oil Spill, November 19-22, 1979. Cendre National pour l'Exploration des Oceans, Brest, France.

Boehm, P.D., J.E. Barak, D.L. Feist, and A. Elskus. 1982. A chemical investigation of the transport and fate of petroleum hydrocarbons in littoral and benthic environments, the *Tsesis* oil spill. Mar. Environ. Res. 6:157-188 .

Boehm, P.D., E. Crecelius, J.M. Neff, C.E. Tuckfield, and M. Steinhauer. 1987. Final Report on Beaufort Sea Monitoring Program: Analysis of Trace Metals and Hydrocarbons from Outer Continental Shelf (OCS) Activities. Report of results of investigations 1984-1986, Contract No. 30163. Submitted to Minerals Management Service, Alaska OCS Region.

Boehm, P.D., L. LeBlanc, J. Trefy, P. Marajh-Whittemore, J. Brown, A. Schutzberg, and A. Kick. 1990. Monitoring Hydrocarbons and Trace Metals in Beaufort Sea Sediments and Organisms, Vols. 1 and 2. Report of results of 1989 investigations, Contract No. 30478. OCS Study MMS 90-0054. Submitted to Minerals Management Service, Alaska OCS Region.

Boersma, P.D. 1986. Ingestion of petroleum by seabirds can serve as a monitor of water quality. Science 231:373-376 .

Boesch, D.F., and MA. Bowen. In press. Bathymetric distribution of assemblages of macrobenthos in the Middle Atlantic Bight., U.S.A. Mar. Ecol. Prog. Ser.

Boesch, D.F., and N.N. Rabalais, eds. 1987. Long-Term Environmental Effects of Offshore Oil and Gas Development. New York: Elsevier Applied Science.

Boesch, D.F., J.N. Butler, D.A. Cacchione, J.R. Geraci J.M. Neff, J.P. Ray, and J.M. Teal. 1987. An assessment of the long-term environmental effects of U.S. offshore oil and gas development activities: Future research needs. Pp. 1-53 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Bonnell, M.L., B. LeBoeuf, M.O. Pierson, D. Dettman, and C.D. Farrens. 1981. Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978: Pinnipeds of the Southern California Bight. Vol. III., Part 1 . Final Report to Minerals Management Service, University of California, Santa Cruz. 535 pp .

Bonnell, M.L., M.O. Pierson, and C.D. Farrens. 1983. Pinnipeds and Sea Otters of Central and Northern California, 1980-83: Status, Abundance and Distribution. Vol. III., Book 1 . Final Report to Mineral Management Service, University of California, Santa Cruz. 220 pp .

Bothner, M.H., R.R. Rendigs, E. Campbell, M.W. Doughten, C.M. Parmenter, M.J. Pickering, R.G. Johnson, and J.R. Gillison. 1983. The Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments During the Second Year of Monitoring. Final Report to Minerals Management Service, U.S. Geological Survey, Woods Hole, Mass. 88 pp .

Bourne, W.R.P. 1976. Seabirds and pollution. Pp. 403-502 in Marine Pollution, R. Johnston, ed. London, England: Academic Press.

Braithwaite, L.F. 1983. The Effects of Oil on the Feeding Mechanism of the Bowhead Whale. Final Report to Bureau of Land Management, Brigham Young University, Provo, Utah. 45 pp .

Brandsma, M.G., and T.C. Sauer. 1983. The OOC Model: Prediction of Short Term Fate of Drilling Fluids in the Ocean. Part two: Model Results. In Proceedings of Minerals Management Service Workshop on Discharges Modeling, February 7-10, 1983, Santa Barbara, Calif.

Brandsma, M.G., L.R. Davis, R.C. Ayers, Jr., and T.C. Sauer, Jr. 1980. Computer model to predict the short-term fate of drilling discharges in the marine environment. Pp. 588-610 in Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, Vol. I . Washington, D.C.: American Petroleum Institute.

Briggs, K.T., E.W. Chu, D.B. Lewis, W.B. Tyler, R.L. Pitman, and G.L. Hunt, Jr. 1981a. Distribution, Numbers and Seasonal Status of Seabirds of the Southern California Bight Area, 1975-1978. Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978, Vol. III . Investigators Reports, Part III: Seabirds, Book I, Chapter I. BLM/YM/SR-81-03. University of California Center for Coastal Marine Studies, Santa Cruz, Calif. 337 pp .

Briggs, K.T., D.B. Lewis, W.B. Tyler, and G.L. Hunt, Jr. 1981b. Brown pelicans in southern California: Habitat use and environmental fluctuations. Condor 83:1-15 .

Briggs, K.T., W.B. Tyler, D.B. Lewis, P.R. Kelly, and DA. Croll. 1983a. Brown pelicans in central and northern California. J. Field Ornithol. 54:353-373 .

Briggs, K.T., W.B. Tyler, D.B. Lewis, and K.T. Dettman. 1983b. Marine Mammals and Seabirds of Central and Northern California, 1980-1983. Status, Abundance and Distribution. Vol. III., Book 3 . Final Report to Minerals Management Service, University of California, Santa Cruz. 246 pp .

Briggs, K.T., W.B. Tyler, D.B. Lewis, and D.R. Carlson. 1987. Bird communities at sea off California: 1975 to 1983. Studies in Avian Biology, No. 11. Los Angeles, Calif.: Cooper Ornithological Society. 74 pp .

Broad, A.C., W. Griffiths, and A.G. Carey, Jr. 1981. Invertebrates. Pp. 27-31 in Proceedings of a Synthesis Meeting: Beaufort Sea - Sale 71 - Synthesis Report, D.W. Norton and W.M. Sackinger, eds. National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program, Juneau, Alaska.

Brown, E.J., and J.F. Braddock. 1990. Sheen screen, a miniaturized most-probable numerical method for enumeration of oil-degrading microorganisms. Appl. Environ. Microbiol. 56:3895-3896 .

Brown, R.G.B. 1986. Revised Atlas of Eastern Canadian Seabirds. I. Shipboard Surveys by R.G.B. Brown. Canadian Wildlife Service, Bedford Institute of Oceanography, Dartmouth, NS. 111 pp .

Buckley, L.J., and R.G. Lough. 1987. Recent growth, biochemical composition, and prey field of larval haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*) on Georges Bank. Can. J. Fish. Aquat. Sci. 44:14-25 .

Buckley, F.G., and C.A. McCaffrey. 1978. Use of Dredged Material Islands by Colonial Seabirds and Wading Birds in New Jersey. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Miss. Tech. Rep. D-78-1. 157 pp . + appendixes.

Butman, B., and J.A. Moody. 1983. Observations of bottom currents and sediment movement along the U.S. East Coast Continental Shelf during winter. Chapter 7 in Environmental

Geologic Studies on the United States Mid and North Atlantic Outer Continental Shelf Area, 1980-1983, Vol. III ., B.A. McGregor, ed. Final Report to U.S. Bureau of Land Management, New York.

Calambokidis, J., J.C. Cubbage, G.H. Steiger, K.C. Balcomb, and P. Bloedel. 1990a. Population estimates of humpback whales in the Gulf of the Farallones, California. Rep. Int. Whal. Commn. (special issue 12) :325-333 .

Calambokidis, J., G.H. Steiger, J.C. Cubbage, K.C. Balcomb, C. Ewald, S. Druse, R. Wells, and R. Sears. 1990b. Sightings and movements of blue whales off central California 1986-88 from photo-identification of individuals. Rep. Int. Whal. Commn. (special issue 12):343-348 .

Caldwell, M.C., and D.K. Caldwell. 1982. A study of the effects of oil ingestion on a bottlenose dolphin, *Tursiops truncatus* . Pp. 224-236 in Study of the Effects of Oil on Cetaceans, J.R. Geraci and D.J. St. Aubin, eds. Final Report prepared for U.S. Department of the Interior, Bureau of Land Management, Washington, D.C. Contract No. AA551-CT9-29. University of Guelph, Ontario, Canada. 274 pp .

Capuzzo, J.M. 1987. Biological effects of petroleum hydrocarbons: Assessments from experimental results. Pp. 343-410 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, ed. New York: Elsevier Applied Science.

Capuzzo, J.M., B.A. Lancaster, and G. Sasaki. 1984. The effects of petroleum hydrocarbons on lipid metabolism and energetics of larval development and metamorphosis in the American lobster *(Homarus americanus)* . Mar. Environ. Res. 14:201-228 .

Carey, A.G., Jr. 1972. Ecological observations on the benthic invertebrates from the central Oregon continental shelf. Pp. 422-443 in The Columbia River Estuary and Adjacent Ocean Waters, A.T. Pruter and D.L. Alverson, eds. Seattle: University of Washington Press.

Carey, A.G., Jr. and R.E. Ruff. 1977. Ecological studies of the benthos in the western Beaufort Sea with special reference to bivalve molluscs. Pp. 505-530 in Polar Oceans: Proceedings of Polar Oceans Conference, M.J. Dunbar, ed. McGill University, Montreal, May 1974. Arctic Institute of North America, Calgary, Canada.

Carey, A.G., Jr., R.E. Ruff, J.G. Castillo, and J.J. Dickinson. 1974. Benthic ecology of the western Beaufort Sea continental margin: Preliminary results. Pp. 665-680 in The Coast and Shelf of the Beaufort Sea, J.C. Reed and J.E. Sater, eds. Proceeding of Symposium, Beaufort Sea Coast and Shelf Research, Arctic Institute of North America, Arlington, Va.

Carey, A.G., Jr., P.H. Scott, and K.R. Walters. 1984. Distributional ecology of shallow southwestern Beaufort Sea (Arctic Ocean) Bivalve Mollusca. Mar. Ecol. Prog. Ser. 17:125-134 .

Carney, R.S. 1987. A review of study designs for the detection of long-term environmental effects of offshore petroleum activities. Pp. 651-696 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Chaney, A.H., B.R. Chapman, J.P. Karges, D.A. Nelson, R.R. Schmidt, and L.C. Thebeau. 1978. Use of Dredged Material Islands by Colonial Seabirds and Wading Birds in Texas. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Miss. Tech Rep. D-78-8. 170 pp . + appendixes.

Chapman, P.M., E.A. Powers, R.N. Dexter, and H.B. Andersen. 1991. Evaluation of effects associated with an oil platform, using the sediment quality triad. Environ. Toxicol. Chem. 10:407-424 .

Cicin-Sain, B. 1986. Offshore Oil Development in California: Challenges to Governments and to the Public Interest. Public Affairs Report. Bulletin of the Institute of Governmental Studies, Vol. 27 , Nos. 1 and 2, February-April 1986 . University of California, Berkeley.

Clarke, K.R. and R.H. Green. 1988. Statistical design and analysis for a 'biological effects' study. Mar. Ecol. Prog. Ser. 46:213-226 .

Coachman, L.K. 1986. Circulation, water masses and fluxes on the southeastern Bering Sea shelf. Cont. Shelf Res. 5:23-108 .

Collard, S.B., and C.N. D'Asaro. 1973. Benthic invertebrates of the eastern Gulf of Mexico. Pp. IIIG-1 to IIIG-28 in A Summary of the Knowledge of the Eastern Gulf of Mexico, J.I. Jones, R.E. Ring, M.O. Rinkel, and R.E. Smith, eds. State University System of Florida, Institute of Oceanography, St. Petersburg, Fla.

Collins, A.G. 1975. Geochemistry of Oilfield Waters. New York: Elsevier Scientific Publishers. 496 pp .

Conan, G. 1982. The long-term effects of the *Amoco Cadiz* oil spill. Phil. Trans. R. Soc. London B 297: 323-333 . Reprinted in The Long-Term Effects of Oil Pollution in Marine Populations, Communities and Ecosystems, R.B. Clark, ed. London: The Royal Society. 259 pp .

Congressional and Administrative News of the U.S. Code, 95th Congress--Second Session. 1978. Pp. 1440-1760 in Legislative History, Vol. 3 . Outer Continental Shelf Lands Act Amendments of 1978. P.L. 95-372. House Report 95-590.

Connors, P.G., C.S. Connors, and K.G. Smith. 1981. Shorebird littoral zone ecology of the Alaskan Beaufort Coast. Final Reports of Principal Investigators 23:295-396 .

Costa, D.P., and G.L. Kooyman. 1981. Effects of oil contamination in the sea otter, Enhydra lutris. Outer Continental Shelf Environmental Assessment Program. Final Reports of Principal Investigators 10:65-107 .

Costa, D.P., and G.L. Kooyman. 1982. Oxygen consumption and temperature regulation in the sea otter and the effect of crude oil fouling. Can. J. Zool. 60:2761-2767 .

Cummings, W.C., D.V. Holliday, and B.J. Lee. 1984. Potential impacts of man-made noise on ringed seals: Vocalizations and reactions. Outer Continental Shelf Environmental Program, Final Reports of Principal Investigators 37:95-230 .

Dames & Moore. 1979. Mississippi Alabama, Florida Outer Continental Shelf Baseline Environmental Survey, MAFLA, 1977/78. Vol. II ., Compendium of Work Element Reports. Final Report, Contract No. AA550-CT7-34 to Bureau of Land Management, New Orleans, La.

Davis, RA., WJ. Richardson, L. Thiele, R. Dietz, and P. Johansen. 1990. State of the Arctic Environment. Report on Underwater Noise. Finnish Initiative on Protection of The Arctic Environment. Copenhagen N, Denmark: Greenland Environmental Research Institute, Tagensvej 135, DK-2200.

Davis, R.W. 1986. Sea Otter Oil Spill Mitigation Study. Final Report to Minerals Management Service, Hubbs Marine Research Institute, San Diego, Calif. 220 pp .

Davis, R.W., T.M. Williams, JA. Thomas, R. Kastelein, and L.H. Cornell. 1988. The effects of oil contamination and cleaning on sea otters (*Enhydra lutris*). II. Metabolism, thermoregulation, and behavior. Can. J. Zool. 66:2782-2790 .

Day, J.H., J.G. Field, and M.P. Montgomery. 1971. The use of numerical methods to determine the distribution of the benthic infauna across the continental shelf of North Carolina. J. Anim. Ecol. 40:93-125 .

DeGange, A.R., and G.A. Sanger. 1987. Marine birds. Pp. 479-524 in The Gulf of Alaska, Physical Environment and Biological Resources, D.W. Hood and S.T. Zimmerman, eds. Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Deriso, R.B. 1989. Evaluation of fishery model aspects addressed in the Bering Sea model of T. Laevastu et al. 1985. Review of Selected Fisheries Issues. Prepared by Technical Resources, Inc. MMS 89-0044. U.S. Department of the Interior, Minerals Management Service, Vienna, Va. 241 pp.

DeRouen, L.R., R.W. Hann, D.M. Casserly, and C. Giammona, eds. 1982. West Hackberry Brine Disposal Project Pre-Discharge Characterization. Report to Department of Energy, Contract No. DE-AC96-80P010228, McNeese State University, Lake Charles, La., and Texas A&M University Research Foundation, College Station.

Dohl, T.P., K.S. Norris, R.C. Guess, J.D. Bryant, and M.W. Konig. 1981. Summary of Marine Mammals and Seabird Surveys of the Southern California Bight Area, 1975-78. Cetacean of the Southern California Bight. Vol. III., Part 2 . Final Report to Bureau of Land Management, University of California, Santa Cruz. 414 pp .

Dohl, T.P., M.L. Bonnell, R.C. Guess, and K.T. Briggs. 1983. Marine Mammals and Seabirds of Central and Northern California, 1980-83. Vol. II ., Synthesis of Findings. Final Report to Bureau of Land Management, University of California, Santa Cruz. 248 pp .

Drury, W.H., C. Ramsdell, and J.B. French. 1981. Ecological studies in the Bering Strait region. Environmental Assessment of the Alaskan Continental Shelf, Final Reports. Biol. Stud. 11:175-487 .

Eldridge, W.D. 1987. Waterbird Utilization of the Coastal Yukon River Delta and Nearshore Waters. Final Report to Outer Continental Shelf Environmental Assessment Program/National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service.

Elmgren, R., S. Hansson, U. Larsson, B. Sundelin, and P.D. Boehm. 1983. The *Tsesis* oil spill: Acute and long-term impact on the benthos. Mar. Biol. 73:51-65 .

Engelhardt, F.R. 1981. Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, *Phoca hispida* . Comp. Biochem. Physiol. 72C:133-136 .

Engelhardt, F.R., J.R. Geraci and T.G. Smith. 1977. Uptake and clearance of petroleum hydrocarbons in the ringed seal, *Phoca hispida* . J. Fish Res. Bd. Can. 34:1143-1147 .

Erwin, R.M. 1979. Coastal Waterbird Colonies: Cape Elizabeth, Maine to Virginia. U.S. Fish Wildlife Service. FWS/OBS-79/10. 212 pp .

Erwin, R.M, and C.E. Korschgen. 1979. Coastal Waterbird Colonies: Maine to Virginia, 1977. An atlas showing colony locations and species composition. U.S. Fish and Wildlife Service Publ. No. FWS/OBS 79-10. NTIS PB80-147-945. U.S. Fish and Wildlife Service, Washington, D.C. 647 pp .

Estes, J.A., and R.J. Jameson. 1983. Summary of Available Population Information on California Sea Otters. POCS Tech. Rep. 83-11. Prepared by U.S. Fish and Wildlife Service for Minerals Management Service. Interagency Agreement No. 14-12-001. 29 pp .

Evans, W.E. 1982. A study to determine if gray whales detect oil. Pp. 47-61 in Study of the Effects of Oil on Cetaceans, J.R. Geraci and D.J. St. Aubin, eds. Final Report, Contract

No. AA551-CT9-29, U.S. Department of the Interior, Bureau of Land Management, Washington, D.C.

Farrington, J.W., A.C. Davis, N.M. Frew, and K.S. Rabin. 1982. No. 2 fuel oil compounds in *Mytilus edulis:* Retention and release after an oil spill. Mar. Biol. 66:15-26 .

Fauchald, K., and G.F. Jones. 1977. Benthic Macrofauna. Chapter 24 in Year I Southern California Baseline Study, Report to Bureau of Land Management, Pacific OCS Office, Los Angeles, California, Contract No. AA551-CT5-52, Science Applications, Inc., La Jolla, Calif.

Fauchald, K., and G.F. Jones. 1978. Variation in Community Structure of Shelf, Slope and Basin Macrofaunal Communities of the Southern California Bight. Chapter 19 in Year II Benthic Study, Report to Bureau of Land Management, Pacific OCS Office, Los Angeles, California, Contract No. AA551-CT6-40, Science Applications, Inc., LaJolla, Calif.

Feder, H.M., and S.C. Jewett. 1980. Distribution, Abundance, Community Structure, and Trophic Relationships of the Nearshore Benthos of the Kodiak Continental Shelf. Environmental Assessment of the Alaskan Continental Shelf, Final Reports. Biol. Stud. 9:1-255 .

Feder H.M., and S.C. Jewett. 1981. Feeding interactions in the eastern Bering Sea with emphasis on the benthos. Pp. 1229-1261 in The Eastern Bering Sea Shelf: Oceanography and Resources, Vols. 1 and 2 , D.W. Hood and J.A. Calder, eds. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Washington, D.C.

Feder, H.M., and G.E.M. Matheke. 1979. Distribution, Abundance, Community Structure, and Trophic Relationships of the Benthic Infauna of the Northeast Gulf of Alaska. Environmental Assessment of the Alaskan Continental Shelf, Final Reports. Biol. Stud. 6:1-256 .

Fletcher, R.I. 1989. Evaluation of the fishery submodels of Reed, French et al. 1982. Pp. 133-167 in Review of Selected Fisheries Issues. Prepared by Technical Resources, Inc., Rockville, Md. OCS Study MMS 89-0044. U.S. Department of the Interior, Minerals Management Service, Vienna, Va. 241 pp .

Flint, R.W. 1981. Gulf of Mexico outer continental shelf benthos: Macroinfaunal environmental relationships. Biol. Oceanogr. 1:135-155 .

Flint, R.W., and J.S. Holland. 1980. Benthic infaunal variability of a transect in the Gulf of Mexico. Estuar. Coast Mar. Sci. 10:1-14 .

Flint, R.W., and N.N. Rabalais. 1980a. Polychaete ecology and niche patterns: Texas continental shelf. Mar. Ecol. Prog. Ser. 3:193-202 .

Flint, R.W., and N.N. Rabalais, eds. 1980b. Environmental Studies, South Texas Outer Continental Shelf, 1975-1977. Vol. III : Study Area Final Reports. Final Report to Bureau of Land Management, University of Texas Marine Science Institute, Port Aransas, Tex. 648 pp .

Flint, R.W., and N.N. Rabalais, eds. 1981. Environmental Studies of a Marine Ecosystem: South Texas Outer Continental Shelf. Austin: University of Texas Press. 272 pp .

Ford, R.G. 1985. A Risk Analysis Model for Marine Mammals and Seabirds: A Southern California Bight Scenario. Final Report prepared for U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles Calif. Contract No. 14-12-0001-30224. Ecological Consulting, San Diego, Calif. 236 pp .

Ford, R.G., J.A. Wiens, D. Heinemann, and G.L. Hunt. 1982. Modelling the sensitivity of colonially breeding marine birds to oil perturbations: Murre and Kittiwake populations on the Pribilof Islands, Bering Sea. J. Appl. Ecol. 19:1-31 .

Fritts, T.H., and R.P. Reynolds. 1981. Pilot Study of the Marine Mammals, Birds and Turtles in OCS Areas of the Gulf of Mexico. Report No. FWS/OBS-81-36. Final Report to Bureau of Land Management , U.S. Fish and Wildlife Service. 139 pp .

Fritts, T.H., A.B. Irvine, R.D. Jennings, LA. Collum, W. Hoffman, and M.A. McGehee. 1983. Turtles, Birds, and Mammals in the Northern Gulf of Mexico and Nearby Atlantic Waters. Final Report to Bureau of Land Management, University of New Mexico, Albuquerque, NM, for U.S. Fish and Wildlife Service, Report FWS/OBS-82/65. 455 pp .

Fry, D.M. 1987. Seabird Oil Toxicity Study. Final Report prepared by Nero and Associates, Inc., Portland, Oreg. for the U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

Fry, D.M., J. Swenson, L.A. Addiego, C.R. Grau, and A. Kang. 1986. Reduced reproduction of Wedge-tailed Shearwaters exposed to weathered Santa Barbara crude oil. Arch. Environ. Contam. Toxicol. 15:453-463 .

Fucik, K.W., and I.T. Show. 1981. Environmental synthesis using an ecosystem model. Pp. 329-353 in Environmental Effects of Offshore Oil Production: The Buccaneer Gas and Oil Field Study, B.S. Middleditch, ed. Chicago, Ill.: Planners Press.

FWS (U.S. Fish and Wildlife Service). 1989. Florida manatee *Trichechus manatus latirostris* recovery plan. Prepared by the Florida manatee recovery team for the U.S. Fish and Wildlife Service, Atlanta, Georgia. 98 pp .

FWS (U.S. Fish and Wildlife Service)/California Department of Fish and Game. 1989. Southern Sea Otter Translocation to San Nicolas Island. Annual Report: August 1988-July 1989. U.S. Fish and Wildlife Service, Ventura Endangered Species Recovery Office, Ventura, Calif.

FWS (U.S. Fish and Wildlife Service)/NMFS (National Marine Fisheries Service). 1991. A Desktop Information System for Colonial Seabirds. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, National Marine Fisheries Service.

Gales, R.S. 1982. Effects of Noise of Offshore Oil and Gas Operations on Marine Mammals: An Introductory Assessment. Research report: 1980-1981. Technical Report 844, Vol. 1 . Prepared for the U.S. Department of the Interior, Bureau of Land Management, Naval Ocean Systems Center, San Diego, Calif.

Gallagher, A.F. 1984. Documentation of the Biological Impact of an Oil Spill Model, BIOS, Part 2: Fish Feeding and Contamination through Consumption - Subroutine FEDOIL. Program Documentation Report No. 22, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Wash.

Gallagher, A.F., and N.B. Pola. 1984. The Uptake and Depuration of Petroleum Hydrocarbons in Marine Species: A Simulation Study of the Uptake and Depuration of Petroleum Hydrocarbons and its Effect on Selected Marine Species in the Bristol Bay Ecosystem. U.S. Department of Commerce, National Marine Fisheries Service, Northwest and Alaska Fisheries Center,.

Gallaway, B.J. 1988. Northern Gulf of Mexico Continental Slope Study, Final Report, Year 4. Vol. I : Executive Summary. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, La.

GAO (General Accounting Office). 1988. Offshore Oil and Gas. Environmental Studies Program Meets Most User Needs but Changes Needed. Report to the Chairman, Environment, Energy, and Natural Resources Subcommittee, Committee on Government Operations, House of Representatives. Washington, D.C. U.S. General Accounting Office. GAO/RCED-88-104.

Garrity, S.D., and S. C. Levings. 1990. Effect of an oil spill on the gastropods of a tropical intertidal reef flat. Mar. Environ. Res. 30:119-153 .

Geraci, J.R., and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. J. Fish. Res. Board Can. 33:1976-1984 .

Geraci J.R., and D.J. St. Aubin. 1980. Offshore petroleum resource development and marine mammals: A review and research recommendations. Mar. Fish. Rev. 42:1-12 .

Geraci J.R., and D.J. St. Aubin. 1982. Study of the Effects of Oil on Cetaceans. Final Report to U.S. Department of the Interior, Bureau of Land Management, Washington, D.C. University of Guelph, Ontario, Canada. 274 pp .

Geraci J.R., and D.J. St. Aubin. 1985. Expanded Studies of the Effects of Oil on Cetaceans. Part 1. Final Report to Minerals Management Service. University of Guelph, Ontario, Canada. 144 pp .

Geraci J.R., and D.J. St. Aubin. 1987. Effects of offshore oil and gas development on marine mammals and turtles. Pp. 587-617 in Long-term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Geraci J.R., and DJ. St. Aubins, eds. 1990. Sea Mammals and Oil: Confronting the Risks. New York: Academic Press.

Gilbert, J.R., V.R. Shurman, and D.T. Richardson. 1979. Gray seals in New England; present status and management alternatives. NTIS PB29-5599. Springfield, Va.: National Technical Information Service. 40 pp .

Goodale, D.R. 1981. The Temporal and Geographic Distribution of Humpback, Fin, and Right Whale Calves. M.S. thesis. Department of Zoology, University of Rhode Island, Kingston, R.I.

Gould, P.J., D.J. Forsell, and C.J. Lensink. 1982. Pelagic Distribution and Abundance of Seabirds in the Gulf of Alaska and Eastern Bering Sea. U.S. Fish and Wildlife Services, Biological Services Program FWS/OBS-82/48.

Grahl-Nielsen, O., J.T. Staveland, and S. Wilhelmsen. 1978. Aromatic hydrocarbons in benthic organisms from coastal areas polluted by Iranian crude oil. J. Fish Res. Bd. Can. 35:615-623 .

Green, R.H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. New York: John Wiley & Sons. 257 pp .

Greene, C.R. 1982. Characteristics of waterborne industrial noise. Pp. 249-346 in Behavior Disturbance Responses and Feeding of Bowhead Whales (*Balaena mysticetus*) in the Beaufort Sea, 1980-81, WJ. Richardson, ed. Final Report to Bureau of Land Management, prepared by LGL Ecological Research Associates, Inc. 445 pp .

Greene, C.R. 1987. Characteristics of Oil Industry Dredge and Drillsite Sounds in the Beaufort Sea. J. Acoust. Soc. Am. 82:1315-1324 .

Griffiths, W.B., and R.A. Buchanan. 1982. Characteristics of bowhead feeding areas. Pp. 347-455 in Behavior, Disturbance Responses, and Feeding of Bowhead Whales (*Balaena mysticetus*) in the Beaufort sea, 1980-81, WJ. Richardson ed. Final Report, LGL Ecological Research Associates, Inc., Bryan, Tex. 456 pp .

Gross, M.G., ed. 1976. Middle Atlantic Continental Shelf and the New York Bight. Am. Soc. Limnol. Oceanogr. Spec. Symp. Vol. 2. 441 pp .

Gruber, J.A. 1981. Ecology of the Atlantic Bottlenose dolphin (*Tursiops truncatus*) in the Pass Cavallo Area of Matagorda Bay, Texas. M.S. thesis . Texas A&M University, College Station. 182 pp .

Gundlach, E.R., and M.O. Hayes. 1978. Vulnerability of coastal environments to oil spill impacts. Mar. Tech. Soc. J. 12:18-27 .

Guzman, J.R., and M.T. Myers. 1982. Ecology and Behavior of Southern Hemisphere Shearwaters (*Genus* puffinus), When Over the Outer Continental Shelf of the Gulf of Alaska and Bering Sea During the Northern Summer (1975-1976), Final Report. 110 pp .

Haensly, W.E., J.M. Neff, J.R. Sharp, A.C. Morris, M.F. Bedgood, and P.D. Boehm. 1982. Histopathology of *Pleuronectes platessa* L. from Aber Wrac'h and Aber Benoit, Brittany, France: Long-term effects of the *Amoco Cadiz* crude oil spill. J. Fish Dis. 5:365-391 .

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea Shelf. Pp. 1091-1103 in The Eastern Bering Sea: Oceanography and Resources, D.W. Hood and J.A. Calder, eds. Vols. 1 and 2 . National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Washington, D.C.

Hann, R.W., Jr., and R.E. Randall, eds. 1980. Evaluation of Brine Discharge from the Bryan Mound Site of the Strategic Petroleum Reserve Program. Report to Department of Energy, Contract No. DE-FC96-79P010114, Texas A&M University Research Foundation, College Station, Tex.

Hardy, J.T., S. Kiesser, L. Antrim, A. Stubin, R. Kocan, and J. Strand. 1987a. The sea-surface microlayer of Puget Sound: Part I. Toxic effects on fish eggs and larvae. Mar. Environ. Res. 23:227-249 .

Hardy, J.T., E A. Crecelius, L.D. Antrim, V.L. Broadhurst, C.W. Apts, J.M. Gurtisen, and T.J. Fortman. 1987b. The sea-surface microlayer of Puget Sound: Part II. Concentrations of contaminants and relation to toxicity. Mar. Environ. Res. 23:251-271 .

Hawkes, J.W. 1980. The effects of xenobiotics on fish tissues: Morphological studies. Fed. Proc. 39:3230-3236 .

Hawkes, J.W., and C.M. Stehr. 1982. Cytopathology of the brain and retina of embryonic surf smelt (*Hypomesus pretiosus*) exposed to crude oil. Environ. Res. 27:164-178 .

Herbst, G.N., A.B. Williams, and B.B. Boothe, Jr. 1979. Reassessment of northern geographic limits for decapod crustacean species in the Carolinian province, U.S.A.; some major range extensions itemized. Proc. Biol. Soc. Wash. 91:989-998 .

Hoffman, W., T.H. Fritts, and R.P. Reynolds. 1981. Whale Sharks Associated with Fish Schools Off South Texas. Northeast Gulf Sci. 5:55-57 .

Holland J.S. 1977. Invertebrate epifauna and macroinfauna. Chapter 9 in Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry. Final Report, Contract No. AA550-CT6-17 to Bureau of Land Management. University of Texas Marine Science Institute, Port Aransas, Tex.

Holland J.S. 1979. Benthic invertebrates: Macroinfauna. Chapter 17 in Environmental Studies, South Texas Outer Continental Shelf, Biology and Chemistry. Final Report, Contract No. AA550-CT7-11 to Bureau of Land Management. University of Texas Marine Science Institute, Port Aransas, Tex.

Hood, D.W., and J.A. Calder, eds. 1981. The Eastern Bering Sea Shelf: Oceanography and Resources. Vols. 1 and 2 . National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Washington, D.C. 1339 pp .

Hunt, G.L., Jr. 1987. Offshore oil development and seabirds: The present status of knowledge and long-term research needs. Pp. 539-586 in Long-Term Environmental Effects of

Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalis, eds. New York: Elsevier Applied Science.

Hunt, G.L., Jr., and D. Schneider. 1987. Scale dependent processes in the physical and biological environment of marine birds. Pp. 7-41 in Trophic Relations of Seabirds, J. Croxall, ed. New York: Cambridge University Press.

Hunt, G.L., Jr., R.L. Pitman, M. Naughton, K. Winnett, A. Newman, P.R. Kelly, and K.T. Briggs. 1979. Summary of Marine Mammals and Seabird Surveys of the Southern California Bight Area: 1975-1978. Vol. III ., Investigator's Reports, Part m. Seabirds of the Southern California Bight, Book II. Distribution, Status, Reproductive Ecology and Foraging Habits of Breeding Seabirds. The Regents of the University of California, Irvine, Calif.

Hunt, G.L. Jr., Z. Eppley, B. Burgeson, and R. Squibb. 1981a. Reproductive Ecology, Foods and Foraging Areas of Seabirds Nesting on the Pribilof Islands, 1975-1979. Environmental Assessment of the Alaska Continental Shelf, Final Reports. Biol. Stud. 12:1-257 .

Hunt, G.L. Jr., P.J. Gould, D.J. Forsell, and H. Peterson. 1981b. Pelagic distribution of marine birds in the eastern Bering Sea. Pp. 649-718 in The Eastern Bering Sea Shelf: Oceanography and Resources, D.W. Hood and J A. Calder, eds. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Rockville, Md.

Hunt, G.L. Jr., J. Kaiwi, and D. Schneider. 1982. Pelagic distribution of marine birds and analysis of encounter probability for the southeastern Bering Sea. Environmental assessment of the Alaska Continental Shelf, Final Reports. Biol. Stud. 16:1-160 .

Hurst, R.J., and N.A. Oritsland. 1982. Polar bear thermoregulation: Effect of oil on the insulative properties of fur. J. Therm. Biol. 7:201-208 .

Iles, T.D., and M. Sinclair. 1982. Atlantic herring: Stock discreetness and abundance. Science 215:627-633 .

Iverson, R.L., L.K. Coachman, R.T. Cooney, T.S. English, J.J. Goering, G.L. Hunt, Jr., M.C. Macauley, C.P. McRoy, W.S. Reeburgh, and T.E. Whitledge. 1979. Ecological significance of fronts in the southeast Bering Sea. Pp. 437-466 in Ecological Processes in Coastal and Marine Systems, R.J. Livingston, ed. New York: Plenum Press.

IWC (International Whaling Commission). 1991. Report of the Scientific Committee of the International Whaling Commission, May 10-20, 1991. Government Conference Centre, Reykjavik, Iceland.

Jackson, G.F., E. Hume, MJ. Wade, and M. Kirsch. 1981. Oil Content in Produced Brine on Ten Louisiana Production Platforms. Report to U.S. Environmental Protection Agency, EPA-600/2-81-209. Municipal Environmental Research Lab., Cincinnati Ohio.

Jackson, J.B.C., J.D. Cubit, B.D. Keller, V. Batista, K. Burns, H.M. Caffey, R.L. Caldwell, S. D. Garrity, C.D. Getter, C. Gonzalez, H.M. Guzman, K.W. Kaufmann, A.H. Knap, S.C. Levings, MJ. Marshall, R. Steger, R.C. Thompson, and E. Weil. 1989. Ecological effects of a major oil spill on panamanian coastal marine communities. Science 243:37-44 .

Jackson, W.B., ed. 1977. Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico, 1976-77. National Oceanic and Atmospheric Administration, NTIS No. PB28-3890. Springfield, Va.: National Technical Information Service.

Johnson, S.R. 1983. Birds and Marine Mammals. Environmental Characterization and Biological use of Lagoons in the Eastern Beaufort Sea, J.C. Truett, ed. Final Reports of Principal Investigators 24:129-579 .

Joint Oceanographic Institutions, Inc. 1990. At the Land-sea Interface: A Call for Basic Research. Joint Oceanographic Institutions, Inc., Washington, D.C.

Jones & Stokes Associates, Inc. 1981. Ecological Characterization of the Central and Northern California Coastal Region. Vol. II., Part 1 , Regional Characterization. U.S. Fish and Wildlife Service, Publ. No. FWS/OBS-80/46.1

Jones, G.F. 1969. The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monogr. Mar. Biol. No. 4:1-219 .

Keller, C.E., J.A. Spendelow, and R.D. Greer. 1984. Atlas of wading bird and seabird nesting colonies in coastal Louisiana, Mississippi and Alabama: 1983. U.S. Fish Wildlife Service, FWS/OBS-84/13. 127 pp .

Kelly, B.P., L.T. Quakenbush, and J.R. Rose. 1986. Ringed Seal Winter Ecology and Effects of Noise Disturbance. Final Report to OCSEAP, Institute of Marine Science, Fairbanks, Alaska. 83 pp .

King, K.A., and C.A. Lefever. 1979. Effects of oil transferred from incubating gulls to their eggs. Mar. Pollut. Bull. 10:319-321 .

Klima, G.F., G.R. Gitschlag, and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Mar. Fish. Rev. 50:33-42 .

Korschgen, C.E. 1979. Coastal Waterbird Colonies: Maine. U.S. Department of the Interior, U.S. Fish and Wildlife Service. 83 pp .

Koster, A.S., and J.A.M. Van den Beggelaar. 1980. Abnormal development of *Dentalium* due to the *Amoco Cadiz* oil spill Mar. Pollut. Bull. 11:166-169 .

Krahn, M.M., and W.D. MacLeod, Jr. 1982. Interlaboratory Comparisons of Selected Trace Hydrocarbons from Marine Sediments, and Automated Extraction of Aromatic Hydrocarbon Metabolites in Fish. Annual Report for Research, Outer Continental Shelf Environmental Assessment Program, Juneau, Alaska.

Krebs, C.T., and K.A. Burns. 1977. Long-term effects of an oil spill on populations of the saltmarsh crab *Uca pugnax* Science 197:484 .

Kuhnhold, W.W. 1974. Investigations on the toxicity of seawater extracts of three crude oils on eggs of cod (*Gadus morhua* L.). Ber. dt. wiss. Kommn. Meeresforsch. 23:165-180 .

Kuhnhold, W.W. 1978. Effects of the water soluble fraction of a Venezuelan heavy fuel oil (No. 6) on cod eggs and larvae. Pp. 126-130 in The wake of the *Argo Merchant,* Proceedings of Symposium, January 1978. Center for Ocean Management Studies, University of Rhode Island, Kingston.

Laevastu, T., R. Marasco, N. Bax, R. Fredin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara, and N. Pola. 1985. Evaluation of the Effects of Oil Development on the Commercial Fisheries in the Eastern Bering Sea. Final Report 36, Parts I and II. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1128 pp .

Lavenbin, R.J., and S.A. Earle. 1975. Proceedings: Recommendations for Baseline Research in Southern California Relative to Offshore Resource Development, December 5-7, 1974. Final Report to Bureau of Land Management. Special Publication, Southern California Academy of Sciences. Los Angeles, Calif. 258 pp .

Lentfer, J.W., ed. 1988. Selected Marine Mammals of Alaska. Species Accounts with Research and Management Recommendations. Washington, D.C.: Marine Mammal Commission.

Lentfer, J.W. 1990. Workshop on Measures to Assess and Mitigate the Adverse Effects of Arctic Oil and Gas Activities on Polar Bears, January 24-25, 1989, Anchorage, Alaska. Washington, D.C.: Marine Mammal Commission. 39 pp .

Levins, R. 1968. Evolution in Changing Environments. Princeton, N.J.: Princeton University Press. ix + 120 pp .

Lewis, S.J., and R.A. Malecki. 1984. Effects of egg oiling on larid productivity and population dynamics. Auk 101:584-592 .

Lie, U., and J.C. Kelley. 1970. Benthic infauna communities off the coast of Washington and in Puget Sound: Identification and distribution of communities. J. Fish Res. Bd. Can. 27:621-651 .

Lie, U., and D.S. Kisker. 1970. Species composition and structure of benthic infauna communities off the coast of Washington. J. Fish Res. Bd. Can. 27:2273-2285 .

Linden, O. 1976. The influence of crude oil and mixtures of crude oil/dispersants on the ontogenic development of the Baltic herring, *Clupea harengus membras* L. Ambio 5:136-140 .

Linden, O., R. Laughlin, Jr., J.R. Sharp, and J.M. Neff. 1980. The combined effect of salinity, temperature and oil on the growth pattern of embryos of the killifish, *Fundulus heteroclitus* Walbaum. Mar. Environ. Res. 3:129-144 .

Ljungblad, D.K., S.E. Moore, J.T. Clarke, and J.C. Bennett. 1987. Distribution, Abundance Behavior and Bioacoustics of Endangered Whales in the Alaskan Beaufort and Eastern Chukchi Seas, 1979-86. Final Report to Mineral Management Service, SEACO, Inc., San Diego, Calif. 187 pp. + appendixes.

Ljungblad, D.K., S.E. Moore, J.T. Clarke, and J.C. Bennett. 1988. Distribution, Abundance Behavior and Bioacoustics of Endangered Whales in the Western Beaufort and Northeastern Chukchi Seas, 1979-87. Final Report to Minerals Management Service, Naval Ocean Systems Center, San Diego, Calif. 103 pp. + appendixes.

Lohoefener, R., W. Hoggard, K. Mullin, C. Roden, and C. Rogers. 1990. Association of Sea Turtles with Petroleum Platforms in the North-Central Gulf of Mexico. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office.

Longwell, A.C. 1977. A genetic look at fish eggs and oil. Oceanus 20:45-58 .

Lowry, L.F., K.J. Frost, and T.J. Burns. 1981a. Trophic relationships among ice inhabiting phocid seals and functionally related marine mammals in the Bering Sea. U.S. Department of Commerce, Environmental Assessment, Alaska Continental Shelf, Final Report. Biol. Stud. 11:97-173 .

Lowry, L.F., K.J. Frost, and T.J. Burns. 1981b. Trophic relationships among ice inhabiting phocid seals and functionally related marine mammals in the Chukchi Sea. U.S. Department of Commerce, Environmental Assessment, Alaska Continental Shelf, Final Report. Biol. Stud. 11:37-95 .

Lyons, W.G. 1980. Molluscan communities of the west Florida shelf. Bull. Am. Malacol. Union 1979:37-40 .

Lyons, W.G., and S.B. Collard. 1974. Benthic invertebrate communities of the eastern Gulf of Mexico. Pp. 157-165 in Proceedings of Marine Environmental Implications of Offshore Drilling in the Eastern Gulf of Mexico, R.E. Smith, ed. State University System of Florida, Institute of Oceanography, St. Petersburg, Fla.

Lysyj, I. 1982. Chemical Composition of Produced Water at Some Offshore Oil Platforms. Final Report Contract No. 68-03-2648. Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati Ohio.

MacLeod, W.D., Jr., D.W. Brown, M.M. Krahn, P. Prohaska, and D. Gennero. 1979. Quality assurance program for trace petroleum component analysis. Environmental Assessment of the Alaskan Continental Shelf. Annu. Rep. 10:479-511 .

MacLeod, W.D., Jr., M.M. Krahn, L.S. Ramos, V.D. Henry, and F.T. Piskur. 1980. Quality assurance program for trace petroleum component analysis. Environmental Assessment of the Alaskan Continental Shelf. Annu. Rep. 7:651-685 .

MacLeod, W.D., Jr., P.G. Prohaska, D.D. Gennero, and D.W. Brown. 1982. Interlaboratory comparisons of selected trace hydrocarbons from marine sediments. Anal. Chem. 54:386-392 .

MacLeod, W.D., Jr., D.W. Brown, A.J. Friedman, O. Maynes, and R.W. Pearce. 1984. Standard analytical procedures of the NOAA National Analytical Facility, 1984-5. Extractable toxic organic compounds, NOAA Tech. Memo NMFS F/NWC6-64. 110 pp .

MacLeod, W.D., Jr., D.W. Brown, A.J. Friedman, O. Maynes, R.W. Pearce, C.A. Wigren, and R.G. Bogar. 1985. Standard Analytical Procedures of the NOAA National Analytical Facility, 1985-6: Extractable Toxic Organic Compounds, Second Edition. NOAA Technical Memorandum NMFS F/NWC-92. 121 pp .

MacLeod, W.D., Jr., A.J. Friedman, and D.W. Brown. 1988. Improved interlaboratory comparisons of polycyclic aromatic hydrocarbons in marine sediment. Mar. Environ. Res. 26:209-221 .

Malins, D.C. 1982. Alterations in the cellular and subcellular structure of marine teleosts and invertebrates exposed to petroleum in the laboratory and field: A critical review. Can. J. Fish. Aquat. Sci. 39:877-889 .

Malins, D.C., H.O. Hodgins, U. Varanasi, S.L. Chan, B.B. McCain, D.D. Weber, and D.W. Brown. 1982. Sublethal Effects of Petroleum Hydrocarbons and Trace Metals, Including Biotransformations, as Reflected by Morphological, Chemical, Physiological, Pathological, and Behavioral Indices. Final Reports 29:1-230 .

Malins, D.C., H.O. Hodgins, U. Varanasi W.D. MacLeod, Jr., B.B. McCain, and S.L. Chan. 1984. Chemical measurements of organic pollutants and effects criteria. Pp. 405-426 in Concepts in Marine Pollution Measurements, H.H. White, ed. Maryland Sea Grant College Publ. No. UM-SG-TS-84-03.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1983. Investigations of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behavior. Final Report. Bolt, Beranek and Newman, Inc., Cambridge, Mass. 377 pp .

Mate, B.R. 1989. Satellite-monitored radio-tracking as a method for studying cetacean movements and behaviour. Rep. Int. Whal. Commn. 42:389-391 .

Mate, B.R. 1991. Application of Remote Methods of Cetacean Tracking: Right Whales. Final Report to U.S. Department of the Interior, Minerals Management Service, Oregon State University, Corvallis, Oregon. 189 pp.

Mate, B.R., and J.T. Harvey. 1981. An Evaluation of Three Radio Tags Applied to Gray Whales and Their Utility in Assessing Whale Movements and Dive Characteristics. Final Report to Minerals Management Service, Oregon State University, Corvallis, Oreg. NTIS No. PB86-16-8861. 68 pp .

Mate, B.R., and J.T. Harvey. 1982. Feasibility of Tracking Whales Using the Argos Satellite System. Final Report, Oregon State University, Marine Science Center, Newport, Oreg. NTIS No. PB86-16-8408. 31 pp .

Maurer, D., and W. Lethem. 1981a. Ecological distribution of polychaetous annelids from the New England outer continental shelf, Georges Bank. Int. Revue ges. Hydrobiol. 66:505-528 .

Maurer, D., and W. Lethem. 1981b. Polychaete feeding guilds from Georges Bank, U.S.A. Mar. Biol. 62:161-171 .

McCain, B.B., H.O. Hodgins, W.D. Gronlund, J.W. Hawkes, D.W. Brown, M.S. Myers, and J.H. Vandermeulen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (*Parophrys vetulus*), and pathological consequences. J. Fish. Res. Board Can. 35:657-664 .

McIntyre, A.D., and J.B. Pearce, eds. 1980. Biological effects of marine pollution and the problem of monitoring. Rapp. P.-V. Reun. Cons. Int. Explor. Mer. 179:1-346 .

Meyer, R.M., and T.M. Johnson. 1990. Fisheries Oceanography, A Comprehensive formulation of technical objectives for offshore application in the Arctic. Workshop Proceedings, April 5-6, 1988, Anchorage, Alaska. OCS Study MMS88-0042, Minerals Management Service, Alaska OCS Region.

Michael, A. 1977. Benthic infauna, 4th quarterly progress report. Pp. 288-327 in New England Outer Continental Shelf Environmental Benchmark. Fourth Quarterly Summary Report to Bureau of Land Management, Energy Resources Co., Inc., Cambridge, Mass.

Michael A.D., C.D. Long, D. Maurer, and R.A. McGrath. 1983. Georges Bank Benthic Infauna Historical Study. Final Report to Minerals Management Service, Taxon, Inc., Salem, Mass. 172 pp .

Middleditch, B.S., ed. 1981. Environmental Effects of Offshore Oil Production. The Buccaneer Gas and Oil Field Study. New York: Plenum Press. 446 pp .

Miles, P.R., C.I. Malme, and W.J. Richardson. 1987. Prediction of Drilling Site-Specific Interaction of Industrial Acoustic Stimuli and Endangered Whales in the Alaskan Beaufort Sea. Final Report to Minerals Management Service, BBN Laboratories, Inc., Cambridge, Mass. 341 pp .

MMS (Minerals Management Service). 1987a. Leasing Energy Resources on the Outer Continental Shelf . U.S. Department of the Interior, Minerals Management Service, Offshore Minerals Management, MS 645, Washington, D.C.

MMS (Minerals Management Service). 1987b. Proposed Outer Continental Shelf Oil and Gas Leasing Program, Mid-1987 to Mid-1992. Final Environmental Impact Statement. OCS EIS-EA, MMS 86-0127. January 1987 . U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

MMS (Minerals Management Service). 1987c. Offshore Environmental Studies Program, Studies Plan, Fiscal Year 1989 (Headquarters Office). OCS Report, MMS 87-0082. U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

MMS (Minerals Management Service). 1988a. ESDS (Environmental Studies Database System). U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

MMS (Minerals Management Service). 1988b. Pacific Outer Continental Shelf Region, Offshore Environmental Studies Program, Environmental Studies Plan, Fiscal Year 1989. OCS Report, MMS 88-0024. U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

MMS (Minerals Management Service). 1988c. Alaska Outer Continental Shelf Region, Alaska Regional Studies Plan, Fiscal Year 1989. U.S. Department of the Interior, Minerals Management Service, Washington, D.C.

MMS (Minerals Management Service). 1990a. Federal Offshore Statistics: 1989. Leasing, Exploration, Production, and Revenues. U.S. Department of the Interior, Minerals Management Service, Offshore Information and Publications, Herndon, Va.

MMS (Minerals Management Service). 1990b. Oil and Gas Leasing/Production Program: Annual Report/FY 1989. U.S. Department of the Interior, Office of Offshore Information and Publications, Minerals Management Service, Herndon, Va.

Monnett, C.W., L.M. Rotterman, C. Stack, D. Monson. 1990. Postrelease monitoring of radio-instrumented sea otters in Prince William Sound. Pp. 400-420 in Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After T/V *Exxon Valdez* Oil Spill into Prince William Sound, Anchorage Alaska, 17-19 April 1990, K. Bayha and J. Kormendy, Technical Coordinators. U.S. Fish and Wildlife Service, Biol. Rep. 90(12). 485 pp .

Montgomery, S., ed. 1987. Report on the 24-26 February Workshop to Assess Possible Systems for Tracking Large Cetaceans. Final Report to Minerals Management Service, Marine Mammal Commission, Washington, D.C. 61 pp .

Murchelano, R.A., and R.E. Wolke. 1985. Epizootic carcinoma in winter flounder, *Pseudopleuronectes americanus* . Science 228:587-589 .

Neff, J.M. 1987. Biological effects of drilling fluids, drill cuttings and produced waters. Pp. 469-538 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, ed. New York: Elsevier Applied Science.

Neff, J.M., N.N. Rabalais, and D.F. Boesch. 1987. Offshore oil land gas development activities potentially causing long-term environmental effects . Pp. 149-173 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, ed. New York: Elsevier Applied Science.

Neff, J.M., M.H. Bothner, N.J. Maciolek, J.F. Grassle, and J. Payne. 1989. Impacts of exploratory drilling for oil and gas on the benthic environment of Georges Bank. Mar. Environ. Res. 27:77-114 .

Nelson, H., R.W. Rowland, S.W. Stoker, and B.R. Larsen. 1981. Interplay of physical and biological sedimentary structures of the Bering continental shelf. Pp. 1265-1296 in The Eastern Bering Sea Shelf: Oceanography and Resources, Vols. 1 and 2 , D.W. Hood and J.A. Calder, eds. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Washington, D.C.

Nisbet, I.C.T. 1989. Guest Editorial: Long-term ecological studies of seabirds. Colon. Waterbirds 12:143-147 .

NMFS (National Marine Fisheries Service). 1975. Environmental Assessment of the Alaskan Continental Shelf, First 18-Month Program, Gulf of Alaska, Southeastern Bering and Beaufort Seas, April 1975. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Proposal submitted to U.S. Department of the Interior, Bureau of Land Management, Washington, D.C.

NMFS (National Marine Fisheries Service). 1988a. FY 88 Technical Development Plan: Arctic Ocean, Bering Sea, Gulf of Alaska. Outer Continental Shelf Environmental Assessment Program, U.S. Department of Commerce, Anchorage, Alaska.

NMFS (National Marine Fisheries Service). 1988b. Status of the Fishery Resources off the Northeastern United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, NOAA Technical Memorandum NMFS-F/NEC-63. 134 pp .

NRC (National Research Council). 1975. Petroleum in the Marine Environment. Washington, D.C.: National Academy Press.

NRC (National Research Council). 1978. OCS Oil and Gas: An Assessment of the Department of Interior Environmental Studies Program. Washington, D.C.: National Academy Press. 109 pp .

NRC (National Research Council). 1983. Drilling Discharges in the Marine Environment. Washington, D.C.: National Academy Press. 180 pp .

NRC (National Research Council). 1985. Oil in the Sea: Inputs, Fates, and Effects. Washington, D.C.: National Academy Press. 601 pp .

NRC (National Research Council). 1989a. The Adequacy of Environmental Information for Outer Continental Shelf Oil and Gas Decisions: Florida and California. Washington, D.C.: National Academy Press. 86 pp .

NRC (National Research Council). 1989b. Using Oil Spill Dispersants on the Sea. Washington, D.C.: National Academy Press. 335 pp .

NRC (National Research Council). 1990a. Assessment of the U.S. Outer Continental Shelf Environmental Studies Program. I. Physical Oceanography. Washington D.C.: National Academy Press. 143 pp .

NRC (National Research Council). 1990b. Decline of the Sea Turtles: Causes and Prevention. Washington, D.C.: National Academy Press. 259 pp .

NRC (National Research Council). 1991. The Adequacy of Environmental Information For Outer Continental Shelf Oil and Gas Decisions: Georges Bank. Washington, D.C.: National Academy Press.

O'Reilly, J.E., T.C. Sauer, R.C. Ayers, Jr., M.G. Brandsma, and R. Meek. 1989. Field verification of the OOC mud discharge model. In Drilling Wastes, F.R. Englehardt, J.P. Ray, and A.H. Gilam, eds. Proceedings of the 1988 International Conference on Drilling Wastes. Calgary, Alberta, Canada 1988, London: Elsevier Applied Science Publishers.

Oritsland, NA., F.R. Engelhardt, F.A. Juck, R.A. Hurst, and P.D. Watts. 1981. (released in 1982). Effect of Crude Oil on Polar Bears. Environmental Studies No. 24, Northern Affairs Program, Department of Indian Affairs and Northern Development , Ottawa. 268 pp .

Owens, E.H., and GA. Robilliard. 1981. Shoreline sensitivity and oil spills: A reevaluation for the 1980's. Mar. Pollut. Bull. 12:75-78 .

Page, G.W., L.E. Stenzel, and D.G. Ainley. 1982. Beached Bird Carcasses as a Means of Evaluating Natural and Human Caused Seabird Mortality. Final Report for U.S. Department of Energy. Contract No. DE-AC03-79EV10254. Springfield, Va.: National Technical Information Service.

Parnell, J.F., MA. Shields, and D. Frierson, Jr. 1985. Hatching success of Brown Pelican (*Pelecanus-occidentalis*) eggs after contamination with oil. Colon. Waterbirds 7:22-24 .

Payne, J.R., C.R. Phillips, and W. Hom. 1987. Transport and transformations: Water column processes. Pp. 175-231 in Long-term Environmental Effects of Offshore Oil and Gas Development, D.F Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Payne, M.R., and LA. Selzer. 1987. Distribution, Abundance and Prey Items of the Harbor Seal *Phoca Vitulina* in Southern New England. Paper presented at the Seventh Biennial Conference on the Biology of Marine Mammals, December 1987, Miami, Fla.

Peakall, D.B., D.J. Hallett, D.S. Miller, R.G. Butler, and W.B. Kinter. 1980. Effects of ingested crude oil on Black Guillemots: A combined field and laboratory study. Ambio 9:28-30 .

Peakall, D.B., D.J. Hallett, J.R. Bend, G.L. Foureman, and D.S. Miller. 1982. Toxicity of Prudhoe Bay crude oil and its aromatic fractions to nestling Herring Gulls. Environ. Res. 27:206-215 .

Peakall, D.B., D.S. Miller, and W.B. Kinter. 1983. Toxicity of crude oils and their fractions to nestling Herring Gulls: Physiological and biochemical effects. Mar. Environ. Res. 8:63-71 .

Peters, C.F., K.O. Richter, DA. Manuwal, and S.G. Herman. 1978. Colonial Nesting Sea and Wading Bird use of Estuarine Islands in the Pacific Northwest. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Miss. Tech. Rep. D-78-17. 179 pp. + appendixes.

Powers, K.D. 1983. Pelagic distributions of marine birds off the northeastern United States. NOAA Technical memorandum. NMFS-F/ NEC-27, U.S. Department of Commerce, Washington, D.C. 201 pp .

Prescott, J.H., and J.R. Gilbert. 1979. East Coast/Gulf Coast Cetacean and Pinniped Workshop, September 1979. Meeting Booklet, New England Aquarium, Boston. 65 pp.

Rabalais, N.N., and D.F. Boesch. 1987. Dominant features and processes of continental shelf environments of the United States. Pp. 71-147 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch, and N.N. Rabalais, eds. New York: Elsevier Applied Science.

Reed, M., D. French, J. Calambokidis, and J. Cubbage. 1986. Simulation Modeling of the Effects of Oil Spills on Population Dynamics of Northern Fur Seals. Final Report to Minerals Management Service, Applied Science Associates, Narragansett, R.I. 142 pp. + appendix.

Reed, M., K. Jayko, A. Bowles, E. Anderson, S. Leatherwood, and M. Spaulding. 1987. Computer Simulation of the Probability that Endangered Whales will Interact with Oil Spills. Final Report to Minerals Management Service, Applied Science Associates, Narragansett, R.I. 182 pp. + appendixes.

Rice, S.D., D.A. Moles, J.F. Karinen, S. Korn, M.G. Carls, C.C. Broderson, J.A. Gharrett, and M.M. Babcock. 1983. Effects of Petroleum Hydrocarbons on Alaskan Aquatic Organisms: A Comprehensive Review of All Oil Effects Research on Alaskan Fish and Invertebrates Conducted by the Auke Bay Laboratory, 1970-81. Outer Continental Shelf Environmental Assessment Program, Environmental Assessment of the Alaskan Continental Shelf. Final Reports 29:311-427 .

Richardson, M.D., A.G. Carey, Jr., and WA. Colgate. 1977. The Effects of Dredged Material Disposal on Benthic Assemblages. Appendix C, Tech. Rep. D-77-30, U.S. Army Corps of Engineers. Waterways Exp. Stn., Vicksburg, Miss. 411 pp .

Richardson, W.J., ed. 1985. Behavior, Disturbance Responses and Distribution of Bowhead Whales, *Balaena Mysticetus* in the Eastern Beaufort Sea, 1980-84. Vol. I ., Final Report to Mineral Management Service. LGL Ecological Research Associates, Inc., Bryan, Tex. 306 pp .

Richardson, W.J., ed. 1987. Importance of the eastern Alaskan Beaufort Sea to Feeding Bowhead Whales, 1985-86. Final Report to Minerals Management Service, LGL Ecological Research Associates, Inc., Bryan, Tex. 547 pp .

Richardson, W.J., J.P. Hickie, RA. Davis, D.H. Thomson, and C.R. Greene. 1989. Effects of Offshore Petroleum Operations on Cold Water Marine Mammals: A Literature Review. API Publ. 4485. Washington, D.C.: American Petroleum Institute. xxv + 385 pp.

Richardson, W.J., C.R. Greene, C.I. Malme, and D.H. Thomson. 1991. Effects of noise on marine mammals. Report to Minerals Management Service, LGL Ecological Research Associates Inc., Bryan, Tex. 462 pp.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-623 .

Riedman, M.L. 1983. Studies on the Effects of Experimentally-Produced Noise Associated with Oil and Gas Exploration and Development on Sea Otters in California. NTIS No. PB86-21-8575. University of California, Santa Cruz, Calif. 49 pp .

Riedman, M.L., and J.A. Estes. 1990. The Sea Otter (*Enhydra lutris*): Behavior, Ecology, and Natural History. Biological Report 90(14) . U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Roesijadi, G., J.W. Anderson, and J.W. Blaylock. 1978. Uptake of hydrocarbons from marine sediments contaminated with Prudhoe Bay crude oil: Influences of feeding type of test species and availability of polycyclic aromatic hydrocarbons. J. Fish. Res. Board Can. 35:608-614 .

Rosenthal, H., and D.F. Alderice. 1976. Sublethal effects of environmental stressors, natural and pollutional, on marine fish eggs and larvae . J. Fish. Res. Board Can. 33:2047-2065 .

Rothschild, B.J. 1986. Dynamics of marine fish populations. Cambridge, Mass.: Harvard University Press. 227 pp .

Rothschild, B.J., and A.J. Mullen. 1985. The information content of stock-and-recruitment data and its non-parametric classification. J. Cons., Cons. Int. Explor. Mer. 42:116-124 .

Saila, S.B., and K. Erzini. 1987. Empirical approach to multispecies stock assessments. Trans. Am. Fish. Soc. 116:601-611 .

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: Long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. J. Mar. Res. 38:265-380 .

Sauer, T.C., Jr. 1981. Volatile liquid hydrocarbon characterization of underwater hydrocarbon vents and formation waters from offshore production operations. Environ. Sci. Technol. 15:917-923 .

Schaaf, W.E., D.S. Peters, D.S. Vaughan, L. Coston-Clements, and C.W. Krouse. 1987. Fish population responses to chronic and acute pollution: The influence of life history strategies. Estuaries 10:267-275 .

Schaffner, L.C., and D.F. Boesch. 1982. Spatial and temporal resource use by dominant benthic Amphipoda (Ampeliscidae and Corophiidae) in the Middle Atlantic Bight outer continental shelf. Mar. Ecol. Prog. Ser. 9:231-243 .

Schneider, D.C., and G.L. Hunt. 1984. A comparison of seabird diets and foraging distribution around the Pribilof Islands, Alaska. Pp. 86-95 in Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships, D. Nettleship, G. Sanger, and P. Springer, eds. Canadian Wildlife Service, Spec. Publ.

Schneider, D.C., G.L. Hunt, and N.M. Harrison. 1986. Mass and energy transfer to seabirds in the southeastern Bering Sea. Cont. Shelf Res. 5:241-257 .

Schreiber, E.A., and R.W. Schreiber. 1980. Effects of impulse noise on seabirds of the Channel Islands. Pp. 138-162 in Potential Effects of Space Shuttle Sonic Booms on the Biota and Geology of the California Channel Islands: Research Reports, J.R. Jehl and C.F. Cooper, eds. Center for Marine Studies, San Diego State University Tech. Report 80-1, San Diego, Calif.

Schreiber, R.W., and EA. Schreiber. 1978. Colonial Bird Use and Plant Succession on Dredged Material Islands in Florida. Vol. I : Sea and Wading Bird Colonies. Tech. Rep. D-78-14. U.S. Army Eng. Waterways Exp. Stn., Vicksburg, Miss. 63 pp. + appendixes.

Senner, S.E. 1979. An evaluation of the Copper River Delta as a critical habitat for migratory shorebirds. Stud. Avian Biol. 2:131-145 .

Sharp, J.R., K.W. Fucik, and J.M. Neff. 1979. Physiological basis of differential sensitivity of fish embryonic stages to oil pollution. Pp. 85-108 in Marine Pollution: Functional Responses, F.J. Vernberg, W.B. Vernberg, and A. Calabrese, eds. New York: Academic Press.

Sindermann, C.J. 1982. Implications of oil pollution in production of disease in marine organisms. Phil. Trans. R. Soc. London B 297:385-399 . Reprinted in The Long-Term Effects of Oil Pollution on Marine Populations, Communities, and Ecosystems, R.B. Clark, ed. London: The Royal Society.

Siniff, D.B., and K. Ralls, eds. 1988. Population Status of California Sea Otters. NTIS No. PB89-19-2983. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region. 391 pp.

Siniff, D.B., T.D. Williams, A.M. Johnson, and D.L. Garshelis. 1982. Experiments on the response of sea otters *Enhydra lutris* to oil contamination. Biol. Conserv. 23:261-272 .

Sissenwine, M.P., and S.B. Saila. 1974. Rhode Island sand dredge spill disposal and trends in the floating trap fishery. Trans. Am. Fish. Soc. 103:498-506 .

Smith, R.L., and J.A. Cameron. 1979. Effect of water soluble fraction of Prudhoe Bay crude oil on embryonic development of Pacific herring. Trans. Am. Fish. Soc. 108:70-75 .

Smith, T.G., and J.R. Geraci. 1975. The Effect of Contact and Ingestion of Crude Oil on Ringed Seals of the Beaufort Sea. Dep. Environ., Victoria, B.C., Beaufort Sea Technical Report No. 5. 66 pp .

Sorensen, P.W., R.J. Medved, M.A.M. Hyman, and H.E. Winn. 1984. Distribution and abundance of cetaceans in the vicinity of human activities along the continental shelf of the northwestern Atlantic. Mar. Environ. Res. 12:69-81 .

Sowls, A.L., S.A. Hatch, and C.J. Lensink. 1978. Catalog of Alaskan Seabird Colonies. U.S. Fish and Wildlife Service Publ. No. FWS/OBS 78-78. U.S. Fish and Wildlife Service, Washington D.C. 32 pp. + maps and tables.

Sowls, A.L., A.R. DeGange, J.W. Nelson, and G.S. Lester. 1980. Catalog of California Seabird Colonies, U.S. Fish and Wildlife Service Publ. No. FWS/OBS 80-37. NTIS PB81-212-599. U.S. Fish and Wildlife Service, Washington, D.C. 371 pp .

Spaulding, M.L., S.B. Saila, M. Reed, et al. 1982. An evaluation of the fishery model components. Assessing the Impact of Oil Spills on a Commercial Fishery. Final Report to New York Outer Continental Shelf Office, U.S. Minerals Management Service, Contract AA851-CTO-75. University of Rhode Island and Applied Science Associates, Inc.

Spies, R.B. 1987. The biological effects of petroleum hydrocarbons in the sea: Assessments from the field and microcosms. Pp. 411-467 in Long-Term Environmental Effects of Offshore Oil and Gas Development, D.F. Boesch and N.N. Rabalais, eds. New York: Elsevier Applied Science.

State University System of Florida. 1977. Baseline Monitoring Studies, Mississippi Alabama, Florida Outer Continental Shelf, 1975-76. Report to Bureau Land Management, Contract No. 08550-CT5-30. State University System of Florida, Institute of Oceanography, St. Petersburg, Florida.

Stegeman, J.J. 1981. Polynuclear aromatic hydrocarbons and their metabolism in the marine environment. Pp. 1-59 in Polycyclic Hydrocarbons and Cancer, Vol. 3 , H.V. Gelboin and P.O.P. Ts'O, eds. New York: Academic Press.

Stenzel, L.E., G.W. Page, H.R. Carter, and D.G. Ainley. 1988. Seabird Mortality in California as Witnessed through 14 years of Beached Bird Censuses. Point Reyes Bird Observatory Report to Gulf of Farallones Marine Sanctuary. 175 pp.

Stewart, B.S., W.E. Evans, and F.T. Aubrey. 1983. Belukha whale (Delphinapterus Leucas) responses to industrial noise in Nushagak Bay, Alaska: 1983. NOAA/OCSEAP Environmental Assessment Alaska Continental Shelf, Final Report of Principal Investigators 43 (1986):587-616 .

Stewart-Oaten, A., W.W. Murdoch, and K. Parker. 1986. Environmental impact assessment: "Pseudoreplication" in time? Ecology 67:929-940 .

Stoker, S. 1981. Benthic invertebrate macrofauna of the eastern Bering/Chukchi continental shelf. Pp. 1069-1090 in The Eastern Bering Sea Shelf: Oceanography and Resources, Vols. 1 and 2 , D.W. Hood and J.A. Calder, eds. National Oceanic and Atmospheric Administration, Office of Marine Pollution Assessment, Washington, D.C.

Stott, G.G., W.E. Haensly, J.M. Neff, and J.R. Sharp. 1983. Histopathologic survey of ovaries of plaice Pleuronectes platessa L. from Aber Wrac'h and Aber Benoit, Brittany, France: Long-Term Effects of the *Amoco Cadiz* Crude Oil Spill J. Fish Dis. 6:429-437 .

Strand, J.A., V.I. Cullinan, E.A. Crecelius, TJ. Fortman, R.J. Citterman, and M.L. Fleischmann. 1990. Monitoring of Olympic National Park Beaches to Determine Fate and Effects of Spilled Bunker C Fuel Oil. Final Report. Prepared for U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, Calif.

Swan, N.P. 1984. Biological Impact of an Oil Spill (BIOS) Model Documentation. Part I. Fish Migrations and Exposure to Contamination. Program documentation No. 21. In Outer Continental Shelf Environmental Assessment Program. Final Reports of Principal Investigators 36 Part 1:181-210 .

Teal, J.M., K. Burns, and J.W. Farrington. 1978. Analyses of aromatic hydrocarbons in intertidal sediments resulting from two spills of No. 2 fuel oil in Buzzards Bay, Massachusetts. J. Fish. Res. Board Can. 35:510-520 .

Tenore, K.R. 1979. Macroinfaunal benthos of South Atlantic/Georgia Bight. Pp. 281-308 in South Atlantic Benchmark Program, Outer Continental Shelf (OCS) Environmental Studies, Vol. 3 , Results of Georgia Bight of South Atlantic Ocean. Final Report. Contract No. AA550-CT7-2 to Bureau of Land Management, Texas Instruments, Inc., Dallas, Tex.

Tetra Tech. 1986. Vulnerability of California Sea Otters and Their Habitat to Oil and Oil Clean Up Practices. Tetra Tech, Inc., Minerals Management Service, Draft Report.

Thomson, D.H., ed. 1984. Feeding ecology of gray whales (Eschrichtius Robustus) in the Chirikof Basin, Summer 1982. Final Report for NOAA, Office of Marine Pollution Assessment, OCSEAP, Anchorage Alaska, by LGL Alaska Research Associates Inc., Anchorage Alaska.

Traecy, S.D. 1988. Aerial Surveys of Endangered Whales in the Beaufort Sea, Fall 1987. Minerals Management Service, Alaska Outer Continental Shelf Region, U.S. Department of the Interior. 76 pp. + appendixes.

Troy, D.M., and S.R. Johnson. 1987. Marine birds. In Environmental Characterization and Biological Utilization of the North Aleutian Shelf Nearshore Zone. LGL Ecological Research Associates. Report to NOS/OMA/OAD on contract number 89-ABC-00125.

Truscott, B., J.M. Walsh, M.P. Burton, J.F. Payne, and D.R. Idler. 1983. Effect of acute exposure to crude petroleum on some reproductive hormones in salmon and flounder. Comp. Biochem. Physiol. 75C:121-130 .

Trustee Council for the *Exxon Valdez* Natural Resource Damage Assessment. 1991. Summary of Effects of the *Exxon Valdez* Oil Spill on Natural Resources and Archaeological Resources. Oil Spill Public Information Center, Anchorage, Alaska.

Tucker and Associates, Inc. 1990. Sea Turtles and Marine Mammals of the Gulf of Mexico. Proceedings of a Workshop held in New Orleans, La., August 1-3, 1989. U.S. Department of the Interior, Minerals Management Service.

Turner, R.E., and D.R. Cahoon. 1988. Causes of Wetland Loss in the Coastal Central Gulf of Mexico. Vol. I: Executive Summary. Coastal Ecology Institute, Louisiana State University. U.S. Department of the Interior, Minerals Management Service.

Underwood, A.J. and C.H. Peterson. 1988. Towards an ecological framework for investigating pollution. Mar. Ecol. Prog. Ser. 46:227-234 .

Vandermeulen, J.H., and J.M. Capuzzo. 1983. Understanding sublethal pollutant effects in the marine environment. Paper No. 9 in Ocean Waste Management: Policy and Strategies, M.A. Champ and M. Trainor, eds. Background papers of symposium, May 2-6, 1983, University of Rhode Island, Kingston.

Varanasi, U., and D.J. Gmur. 1981. Hydrocarbons and metabolites in English sole (*Parophrys vetulus*) exposed simultaneously to ^{3}H-benzo [a]pyrene and ^{14}C-naphthalene in oil-contaminated sediment. Aquat. Toxicol. 1:49-67 .

Varoujean, D.H. 1978. Seabird Colony Catalog: Washington, Oregon and California. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Varoujean, D.H., D.A. Schroeder, and D.M. Power. 1983. Seabird-Oil Spill Behavior Study, Vols. 1-3 . Contract No. SBO-408a-80-C-SSO/ AA851-CTO-70. Final report prepared by Nero and Associates, Inc. for U.S. Department of the Interior, Bureau of Land Management, Pacific OCS Office, Los Angeles, Calif.

Waldichuk, M. 1980. Retrospect of the *Ixtoc I* blowout. Mar. Poll. Bull. 11:184-186 .

Wanless, S., D.D. French, M.P. Harris, and D.R. Longslow. 1982. Detection of annual changes in the numbers of cliff-nesting seabirds in Orkney 1976-80. J. Anim. Ecol. 51:785-795 .

Ward, C.H., M.E. Bender, and D.J. Reish, eds. 1979. The Offshore Ecology Investigation. Effects of Oil Drilling and Production in a Coastal Environment. Rice Univ. Studies 65:1-589 .

Ward, D.M., R.M. Atlas, P.D. Boehm, and J.A. Calder. 1980. Microbial biodegradation and the chemical evolution of *Amoco Cadiz* oil pollutants. Ambio 9:277-283 .

Watkins, W.A. 1981. Radio Tagging of Finback Whales: Iceland, June-July 1980. Final Report, Minerals Management Service, Outer Continental Shelf Study. Woods Hole Oceanographic Institution, Massachusetts. 46 p p.

Wenner, E.L., and D.F. Boesch. 1979. Distribution patterns of epibenthic decapod Crustacea along the shelf-slope coenocline, Middle Atlantic Bight, U.S.A. Bull. Biol. Soc. Wash. 3:106-113 .

Wigley, R.L. 1965. Density-dependent food relationships with references to New England ground fish. ICNAF Spec. Publ. 6:51-514 .

Wigley, R.L., and A.D. McIntyre. 1964. Some quantitative comparisons of offshore meiobenthos and macrobenthos south of Martha's Vineyard. Limnol. Oceanogr. 9:485-493 .

Wigley, R.L., and R.B. Theroux. 1976. Macrobenthic Invertebrate Fauna of the Middle Atlantic Bight Region: Part II. Faunal Composition and Quantitative Distribution. National Marine Fisheries Center, Woods Hole, Mass. 395 pp .

Wigley, R.L., and R.B. Theroux. 1981. Macrobenthic Invertebrate Fauna of the Middle Atlantic Bight Region. Faunal Composition and Quantitative Distribution. Prof. Pap. U.S. Geological Survey 529-N.

Williams, A.B., L.R. McCloskey, and I.E. Gray. 1968. New records of brachyuran decapod crustaceans from the continental shelf off North Carolina, U.S.A. Crustacean 15:41-66 .

Williams, T.M., R.A. Kastelein, R.W. Davis, and JA. Thomas. 1988. The effects of oil contamination and cleaning on sea otters (*Enhydlutris*). I. Thermoregulatory implications based on pelt studies. Can. J. Zool. 66:2776-2781 .

Winn, H.E., ed. 1982. A Characterization of Marine Mammals and Turtles in the Mid-Atlantic and North Atlantic Areas of the U.S. Outer Continental Shelf . Final Report to Minerals Management Service. University of Rhode Island, Kingston. 450 pp .

Winn, H.E., J.H.W. Hain, M A.M. Hyman, and G.P. Scott. 1987. Whales, dolphins, and porpoises. Pp. 375-382 in Georges Bank, R.H. Backus, ed. Cambridge, Mass.: MIT Press. 593 pp .

Witham, R. 1981. Disruption of sea turtle habitat with emphasis on human influence. Pp. 519-522 in Biology and Conservation of the Sea Turtles, KA. Bjorndal, ed. Washington, D.C.: Smithsonian Institution Press.

Woody, J.B. 1986. Kemp's Ridley Sea Turtle. Pp. 919-931 in Audubon Wildlife Report 1986, A.S. Eno, ed. New York: National Audubon Society.

Woodward-Clyde Consultants and Continental Shelf Assoc., Inc. 1983. Southwest Florida Shelf Ecosystems Study: Year I. Final Report. Contract No. 14-12-0001-29142 to Minerals Management Service, Gulf of Mexico OCS Region, Metairie, La.

Wursig, B., E.M. Dorsey, M.A. Fraker, R.S. Payne, and WJ. Richardson. 1985. Behavior of bowhead whales, *Balaena mysticetus,* summering in the Beaufort Sea: A Description . Fish. Bull. 83:357-377 .

Appendix A

Commission on Physical Sciences, Mathematics, and Resources

Norman Hackerman (*Chairman*), Robert A. Welch Foundation, Houston
Robert C. Beardsley, Woods Hole Oceanographic Institution, Woods Hole
B. Clark Burchfiel, Massachusetts Institute of Technology, Cambridge
George F. Carrier, Harvard University, Cambridge
Ralph J. Cicerone, National Center for Atmospheric Research, Boulder
Herbert D. Doan, The Dow Chemical Co. (retired), Midland, Michigan
Peter S. Eagleson, Massachusetts Institute of Technology, Cambridge
Dean E. Eastman, IBM T.J. Watson Research Center, Yorktown Heights, New York
Marye Anne Fox, University of Texas, Austin
Gerhart Friedlander, Brookhaven National Laboratory Associated Universities, Inc., Long Island
Lawrence W. Funkhouser, Chevron Corp. (retired), Menlo Park, CA
Phillip A. Griffiths, Duke University, Durham
Neal F. Lane, Rice University, Houston
Christopher F. McKee, University of California at Berkeley
Richard S. Nicholson, American Association for the Advancement of Science, Washington, D.C.
Jack E. Oliver, Cornell University, Ithaca
Jeremiah P. Ostriker, Princeton University Observatory, Princeton
Philip A. Palmer, E.I. du Pont de Nemours & Co., Newark, DE
Frank L. Parker, Vanderbilt University, Nashville
Denis J. Prager, MacArthur Foundation, Chicago
David M. Raup, University of Chicago
Roy F. Schwitters, Superconducting Super Collider Laboratory, Dallas
Larry L. Smarr, University of Illinois at Urbana-Champaign
Karl K. Turekian, Yale University, New Haven
Staff
Myron F. Uman, Acting Executive Director

Appendix B

Ecology Study Contracts Awarded by Minerals Management Service, 1973-1989

Compiled by the Ecology Panel from information provided by MMS.

Contract Number	Region	Title	Year	Amount ($)
12975	Alaska	Systematic Aerial Survey for Bowhead Whales in the Canadian Beaufort Sea	1986	9,771
14887	Alaska	Potential Impacts of Human Activities on Feeding Behavior, Energetics, and Habitats of Molting Pacific Black Brants at Teshekpuk Lake	1987	210,000
14908	Alaska	Pacific Walrus Population Study	1987	19,709
29013	Alaska	Project Whales (includes IA8-55, IA9-22)	1980	820,084
29015	Alaska	Whale Tagging Program	1980	227,102
29033	Alaska	Investigation of Potential Effects of Acoustic Stimuli Associated with Oil and Gas Exploration/Development on Behavior of Migratory Gray and Humpback Whales	1982	865,809
29042	Alaska	Monitoring Movements of Whales in Adjacent OCS Lease Areas	1979	668,130
29043	Alaska	Whales in the Beaufort Sea	1980	273,776
29045	Alaska	Aircraft Support in Beaufort Sea	1980	311,000
29046	Alaska	Tissue Analysis of Endangered Whales in the Beaufort Sea	1980	349,891
29051	Alaska	The Possible Effects of Acoustic and Other Stimuli Associated with Oil and Gas Exploration/Development on Behavior of the Bowhead Whale	1980	3,011,050
29052	Alaska	Effects of Oil on the Feeding Mechanism of the Bowhead Whale	1980	44,172
29056	Alaska	Presence/Absence of Bowhead and Gray Whales in Beaufort and Norton Basins	1981	345,305
29064	Alaska	Aerial Surveys of Endangered Whales, Northern Bering, Chukchi and Beaufort Seas (includes IA2-51/29074 award of $100,000)	1982	638,012

Contract Number	Region	Title	Year	Amount ($)
29065	Alaska	Aerial Surveys of Endangered Whales in the Beaufort Sea and Aerial Surveys of Walrus Populations	1982	528,583
29066	Alaska	Aircraft Support (N642) for Marine Mammal Aerial Surveys	1982	155,554
29073	Alaska	Trophic Relationships, Habitat Use Among Phocid Seals (Support for RU-232 Funds from Environmental Operations-MMS)	1982	50,000
30031	Alaska	Aerial Surveys of Endangered Whales in the Beaufort, Chukchi, and Northern Bering Seas (FY 1983)	1983	1,308,718
30035	Alaska	Aircraft Support for Endangered Whale Surveys	1983	511,389
30076	Alaska	Computer Simulation of Whale Interactions with Oil Spills	1983	282,592
30144	Alaska	Monitoring of Nesting Seabird Colonies—Pribilof Islands and Cape Peirce	1984	141,468
30145	Alaska	Simulation Modeling of Effects of Oil Spills on Northern Fur Seals	1984	112,045
30163	Alaska	Beaufort Sea Monitoring Plan Program: Analysis of Trace Metals and Hydrocarbons from OCS Activities	1984	1,189,355
30170	Alaska	Aerial Surveys of Endangered Whales in Alaska	1984	859,383
30182	Alaska	Monitoring of the Winter Presence of Bowhead Whales in the Navarin Basin Through Association with Sea Ice	1984	74,098
30208	Alaska	Development of Visual Matrix Charts Which Categorize Research Literature on Endangered Mammals	1984	74,689
30230	Alaska	Aerial Survey of Endangered Whales, Beaufort, Chukchi, and Bering Seas	1985	595,545
30233	Alaska	Food Organisms of Bowhead Whales—Importance of the E. Beaufort to the Feeding of Bowhead Whales	1985	1,557,532
30237	Alaska	Monitoring of Seabird Colonies in the Alaskan Outer Continental Shelf Lease Areas	1985	346,756
30290	Alaska	Aircraft Services for Aerial Surveys of Endangered Whales in the Northern Bering, Chukchi, and Beaufort Seas	1986	369,662
30291	Alaska	Aerial Survey of Endangered Whales in the Bering, Chukchi, and Beaufort Seas	1986	309,135
30295	Alaska	Prediction of Site-Specific Interaction of Acoustic Stimuli and Endangered Whales as Related to Drilling Activities—Beaufort Sea	1985	923,890
30299	Alaska	Workshop on Monitoring Effects of Oil and Gas Development in Bering Sea	1986	116312

Contract Number	Region	Title	Year	Amount ($)
30320	Alaska	Aerial Survey of Endangered Whales	1986	535,930
30332	Alaska	Behavior and Energetics of Pacific Black Brant and Other Geese	1986	240,000
30356	Alaska	Aircraft Services for Aerial Surveys of Endangered Whales in the North Bering, Chukchi, and Beaufort Seas	1987	502,163
30361	Alaska	Synthesis of Information on the Effects of Noise and Disturbance on Major Haulout Concentrations of Bering Sea Pinnipeds	1987	59,993
30365	Alaska	Potential Acoustic Disturbance to Marine Mammals in Alaska	1987	124,954
30370	Alaska	Aerial Survey of Endangered Whales, Beaufort, Chukchi and Bering Seas	1987	198,599
30390	Alaska	Comparison of Behavior of Bowhead Whales of the Davis Straits and Western Arctic Stocks	1987	280,042
30391	Alaska	Monitoring Seabird Populations Near Offshore Activities	1987	292,818
30411	Alaska	Development of a Tag to Monitor Migratory Patterns and Habitat Use of Marine Mammals	1988	374,530
30412	Alaska	Effects of Production Activities on Bowhead Whales	1988	704,336
30421	Alaska	Aircraft Services for Aerial Surveys of Endangered Whales in the North Bering, Chukchi and Beaufort Seas	1988	190,116
30472	Alaska	Stable Isotope Analysis of 1987 and 1988 Zooplankton and Bowhead Whale Tissues	1989	129,934
30478	Alaska	Monitor Hydrocarbon and Trace Metals in Beaufort Sea Sediments and Organisms	1989	274,061
30490	Alaska	Aerial Surveys of Arctic Whales	1989	348,904
60090	Alaska	Commercial Fisheries Harvest Data	1987	15,500
AK001	Alaska	Aerial Survey of Endangered Whales (Inhouse)	1987	14,600
CT8-54	Alaska	Historical Information on Bowhead Whales and Other Resources in the Beaufort Sea Area	1978	35,390
IA1-06	Alaska	Aircraft Support (Logistic Support for IA1-5)	1981	609,952
IA9-09	Alaska	Presence or Absence and Behavior of Endangered Whales in the Beaufort Sea (includes IA9-20 award of $57,966)	1979	107,966
IA9-17	Alaska	Migration, Distribution, Feeding Habits, and Ecology of Bowhead, Gray, and Right Whales	1979	618,700
MMS-001	Alaska	Aerial Survey of Endangered Whales in the Bering, Chukchi, And Beaufort Seas	1988	35,952
MU0-15	Alaska	Water Bird Habitat Study, Kodiak Island	1980	52,600
RU-003	Alaska	Identification, Documentation and Delineation of Coastal Migratory Bird Habitats in Alaska	1979	689,709

Contract Number	Region	Title	Year	Amount ($)
RU-005	Alaska	Distribution, Abundance, Community Structure, and Trophic Relationships of Nearshore Benthos	1981	1,973,581
RU-006	Alaska	Distribution, Composition, and Variability of Western Beaufort and Northern Chukchi Benthos	1982	1,202,616
RU-007	Alaska	Summarization of Existing Literature and Unpublished Data on the Distribution, Abundance, and Life Histories of Benthic Organisms (Beaufort Sea)	1977	91,140
RU-019	Alaska	Finfish Resource Surveys in Norton Sound and Kotzebue Sound	1979	1,038,705
RU-023	Alaska	Yakutat Bay Benthos Study	1975	6,124
RU-024	Alaska	Razor Clam Distribution and Population Assessment Study	1977	99,114
RU-027	Alaska	Study of the Littoral Zone of the Kenai Peninsula	1975	66,139
RU-029	Alaska	Assessment of Potential Interactions of Microorganisms and Pollutants Resulting from Petroleum Development on the Alaska OCS (RU-029/030)	1982	1,405,335
RU-034	Alaska	Analysis of Marine Mammal Remote Sensing Data	1975	18,372
RU-038	Alaska	A Census of Seabirds on the Pribilof Islands	1975	49,459
RU-043	Alaska	Trace Hydrocarbon Analysis in Sea Ice and at the Sea Ice-Water Interface and Analysis of Individual High Molecular Weight Aromatic Hydrocarbons	1977	615,036
RU-058	Alaska	A Description and Numerical Analysis of the Factors Affecting the Processes of Production in the Gulf of Alaska	1975	97,677
RU-059	Alaska	Coastal Morphology, Sedimentation, and Oil Spill Vulnerability	1981	1,182,914
RU-062	Alaska	The Physiological Effect of Acute and Chronic Exposure to Hydrocarbons and Petroleum on the Nearshore Fishes of the Bering Sea	1975	73,739
RU-064	Alaska	Review of Literature and Historical Data on Non-Salmonid Pelagic Fisheries Resources of the Eastern Bering Sea and Gulf of Alaska	1975	57,718
RU-067	Alaska	Baseline Characterization of Marine Mammals	1977	394,432
RU-068	Alaska	Seasonal Distribution and Relative Abundance of Marine Mammals in the Gulf of Alaska	1976	316,094
RU-069	Alaska	Abundance and Seasonal Distribution of Bowhead and Belukha Whales in the Arctic Oceans (RU-069/070)	1977	320,603
RU-071	Alaska	Effects of Oiling on Thermoregulation in Sea Otters	1977	142,150

Contract Number	Region	Title	Year	Amount ($)
RU-072	Alaska	Lethal and Sublethal Effects on Selected Alaskan Marine Species After Acute and Long-Term Exposure to Oil and Oil Components	1982	2,740,334
RU-073	Alaska	Sublethal Effects-Petroleum Hydrocarbons: Biotransformations Reflected by Morphological, Chemical, Physiological, Pathological, Behavioral Indices RU-073/074	1982	3,221,367
RU-075	Alaska	Assessment of Available Literature on the Effects of Oil Pollution on Biota in Arctic and Subarctic Waters	1975	50,523
RU-077	Alaska	Ecosystems Dynamics Modeling-Eastern Bering Sea	1979	374,688
RU-078	Alaska	Baseline Characterization of Littoral Biota in the Gulf of Alaska and Bering Sea (RU-078/079)	1977	2,164,814
RU-083	Alaska	Pelagic Distribution of Seabirds in the Southeastern Bering Sea	1982	1,035,265
RU-087	Alaska	The Interaction of Oil with Sea Ice	1982	660,071
RU-096	Alaska	Evolution, Pathobiology, and Breeding Ecology of the Gulf of Alaska Herring Gull Group	1977	74,120
RU-108	Alaska	Simulation Modeling of Marine Bird Population Energetics, Food Consumption, and Sensitivity to Perturbations	1975	424,639
RU-123	Alaska	Acute Effects of Petroleum to Pacific Herring Roe in the Gulf of Alaska	1975	94,922
RU-152	Alaska	The Distribution, Composition, Transport, and Hydrocarbon Absorption Characteristics of Suspended Matter in the Gulf of Alaska and Lower Cook Inlet	1980	1,277,489
RU-162	Alaska	Natural Distribution of Heavy Trace Metals and Environmental Background in Three Alaskan Shelf Areas	1977	1,374,924
RU-172	Alaska	Shorebird Dependence on Arctic Littoral Habitats	1982	537,784
RU-174	Alaska	Baseline Studies of Resources of the Gulf of Alaska Shelf and Slope	1977	123,089
RU-175	Alaska	Baseline Studies of Fish and Shellfish Resources of the Eastern Bering Sea, Norton Sound, and Southeastern Chukchi Sea	1977	1,071,466
RU-183	Alaska	Acute and Chronic Toxicity of Seawater Extracts of Alaskan Crude Oil to Zoea of Dungeness Crab	1975	62,307
RU-190	Alaska	Study of Microbial Activity and Crude Oil Microbial Interactions with the Waters and Sediments of Cook Inlet and the Beaufort Sea	1981	1,105,863
RU-194	Alaska	Morbidity and Mortality of Marine Mammals	1980	617,714
RU-196	Alaska	Distribution, Abundance, and Feeding Ecology of Birds Associated with Pack Ice (RU-196/330)	1982	656,813

Contract Number	Region	Title	Year	Amount ($)
RU-215	Alaska	Avifaunal Utilization of the Offshore Island Near Prudhoe Bay, Alaska	1975	6,279
RU-229	Alaska	Biology of the Harbor Seal	1979	421,751
RU-230	Alaska	The Natural History and Ecology of the Bearded Seal and the Ringed Seal	1975	750,990
RU-231	Alaska	An Aerial Census of Spotted Seals	1975	27,558
RU-232	Alaska	Trophic Relationships, Habitat Use, and Winter Ecology of Ice-Inhabiting Phocid Seals and Functionally Related Marine Mammals in the Arctic	1982	2,294,423
RU-233	Alaska	Beaufort Sea Estuarine Fishery Study	1977	368,146
RU-237	Alaska	Ecology of Seabirds in the Bering Strait Region	1981	428,550
RU-239	Alaska	Ecology and Behavior of Southern Hemisphere Shearwaters and Other Seabirds When over the OCS of the Bering Sea and Gulf of Alaska	1977	25,100
RU-240	Alaska	Assessment of the Distribution and Abundance of Sea Otters Along the Kenai Peninsula, Kamishak Bay, and the Kodiak Archipelago	1975	16,994
RU-241	Alaska	Distribution and Abundance of Sea Otters in Southwest Bristol Bay	1975	15,310
RU-243	Alaska	Population Assessment, Ecology, and Trophic Relationships of Steller Sea Lions in the Gulf of Alaska	1980	1,186,713
RU-248	Alaska	The Relationships of Marine Mammal Distributions, Densities, and Activities to Sea Ice Conditions (RU-248/249)	1977	469,205
RU-275	Alaska	Natural Distributions and Dynamics of Hydrocarbons on the Alaskan OCS	1979	1,856,280
RU-281	Alaska	Distribution, Abundance, Diversity, and Productivity of Benthic Organisms in the Gulf of Alaska (RU-281/282/301)	1975	157,458
RU-284	Alaska	Food and Feeding Relationships in the Benthic and Demersal Fishes of the Gulf of Alaska and Bering Sea	1977	160,101
RU-285	Alaska	Preparation of Illustrated Keys to Skeletal Remains and Otoliths of Forage Fishes of the Gulf of Alaska and Bering Sea	1975	67,364
RU-305	Alaska	Sublethal Effects on Seagrass Photosynthesis	1975	118,958
RU-318	Alaska	Preparation of Illustrated Keys to Skeletal Remains and Otoliths of Forage Fishes of the Gulf of Alaska	1975	45,402
RU-332	Alaska	Determine the Incidence and Pathology of Marine Fish Diseases in the Gulf of Alaska, Bering and Beaufort Seas	1977	330,613

Contract Number	Region	Title	Year	Amount ($)
RU-337	Alaska	Seasonal Distribution and Abundance of Marine Birds	1975	1,434,830
RU-339	Alaska	Review and Analysis of Literature and Unpublished Data on Marine Birds	1975	66,292
RU-340	Alaska	Migration of Birds in Alaskan Marine Waters Subject to Influence by OCS Development	1975	33,222
RU-341	Alaska	Feeding Ecology and Trophic Relationships of Alaskan Marine Birds	1975	2,465,747
RU-342	Alaska	Population Dynamics of Marine Birds	1975	500,437
RU-343	Alaska	Catalog of Seabird Colonies	1977	46,389
RU-348	Alaska	Literature Search and Data Conversion on Density Distribution of Fishes of the Beaufort Sea	1975	30,620
RU-349	Alaska	Alaska Marine Ichthyoplankton Key	1975	91,860
RU-353	Alaska	Description of the Present Status of Knowledge of the Distribution, Relative Abundance, and Migratory Routes of Salmonids—Gulf of Alaska and Bering Sea	1977	68,895
RU-354	Alaska	Review of Literature and Archived Data, on Non-Salmonid Pelagic Fishes in the Eastern Bering Sea	1975	73,181
RU-356	Alaska	Environmental Assessment of Selected Habitats in Arctic Littoral Systems	1981	2,369,584
RU-359	Alaska	Plankton Studies in the Beaufort, Chukchi, and Bering Seas	1981	1,006,816
RU-380	Alaska	Ichthyoplankton of the Eastern Bering Sea	1977	151,500
RU-389	Alaska	Transport, Retention, and Effects of Toxic Petroleum Hydrocarbons in Experimental Food Chains	1977	131,819
RU-413	Alaska	Trace Metal Content of Bottom Sediment in the Northern Bering Sea	1977	43,139
RU-417	Alaska	Reconnaissance of the Epibenthic and Intertidal Biota in Lower Cook Inlet	1979	803,828
RU-423	Alaska	Influence of Petroleum on Egg Formation and Embryonic Development in Seabirds	1977	90,280
RU-424	Alaska	Plankton/Icthyoplankton of the Gulf of Alaska	1981	962,425
RU-425	Alaska	Source, Composition, and Flux of Organic Detritus in Lower Cook Inlet	1979	824,719
RU-426	Alaska	Zooplankton and Micronecton in the Bering, Chukchi, and Beaufort Seas	1977	544,156
RU-427	Alaska	Ice-edge Ecosystem Study. Primary Productivity, Nutrient Cycling, and Organic Matter Transport	1977	891,367
RU-441	Alaska	Avian Community Ecology on Espenberg Peninsula, Kotzebue Sound, Alaska	1977	236,180

Contract Number	Region	Title	Year	Amount ($)
RU-447	Alaska	Site-Specific Studies of Populations, Community Structure, and Ecology of Marine Birds at King and St. Lawrence Islands	1977	121,255
RU-454	Alaska	Accumulation of Organic Constituents and Heavy Metals from Petroleum-Impacted Sediments by Marine Detritivores	1979	655,276
RU-458	Alaska	Avian Community Ecology in Norton Bay, Alaska	1977	125,542
RU-460	Alaska	Analysis of Populations and Trophics at Large Seabird Colonies in the Northern Bering and Eastern Chukchi Seas	1983	152,600
RU-460	Alaska	Analysis of Populations and Trophics at Large Seabird Colonies in the Northern Bering and Eastern Chukchi Seas	1982	528,555
RU-467	Alaska	Arctic Ecosystems Analysis	1981	3,754,001
RU-470	Alaska	Surveys of Populations, Community Structure, and Ecology of Marine Birds on St. Lawrence Island	1977	81,602
RU-480	Alaska	Characterization of Organic Matter in Sediments from the Gulf of Alaska, Bering and Beaufort Seas	1981	769,747
RU-481	Alaska	A Survey of Cetaceans in Prince William Sound and Adjacent Vicinity—Their Numbers and Seasonal Movements	1977	235,571
RU-485	Alaska	Assessment of Fish Populations in Pelagic and Littoral Waters of Three Bays on the Southeast Coast of Kodiak	1975	199,336
RU-486	Alaska	Demersal Fish and Shellfish Assessment in Selected Estuary Systems of Kodiak	1977	167,130
RU-488	Alaska	Characterization of Coastal Habitat for Migratory Birds: Northern Bering Sea	1977	67,880
RU-490	Alaska	Larval Juvenile and Forage Fish and Planktonic Stages of Commercial Crabs and Shrimp in Lower Cook Inlet	1975	13,779
RU-500	Alaska	Activity-Directed Fractionation of Petroleum Samples	1977	276,300
RU-502	Alaska	Trawl Survey of the Benthic Epifauna of Chukchi Sea and Norton Sound	1977	72,177
RU-506	Alaska	Major, Minor and Element Trace Analysis of Selected Bering Sea Sediment Samples by Instrumental Neutron Activation Analysis	1977	74,701
RU-512	Alaska	Pelagic and Demersal Fish Resource Assessment in the Lower Cook Inlet Estuary System	1979	865,495
RU-517	Alaska	The Distribution, Abundance, and Diversity of Benthic Organisms in Two Bays of Kodiak Island, Alaska	1980	41,822
RU-537	Alaska	Nutrient Dynamics and Trophic System Energetics in Nearshore Beaufort Sea Waters	1981	1,179,937

Contract Number	Region	Title	Year	Amount ($)
RU-542	Alaska	Evaluation of Habitats, Temporal and Spatial Distribution, Relative Abundance, and Trophic Interactions of Shallow Water Fish Communities—NE Gulf of Alaska	1979	333,428
RU-551	Alaska	Seasonal Composition, Food Web and Relationships of Marine Organisms in the Nearshore Zone	1979	966,617
RU-552	Alaska	Seasonal Composition and Food Web Relationships of Marine Organisms in the Nearshore Zone	1979	1,012,768
RU-553	Alaska	Seasonal Composition and Food Web Relationships of Marine Organisms in the Nearshore Zone	1980	1,775,904
RU-556	Alaska	Trace Metals in Bottom Sediments of the Southern Bering Sea	1977	25,425
RU-563	Alaska	Taxonomic Identification and Archiving of Biological Specimens	1987	57,726
RU-591	Alaska	Seasonal Use of Coastal Habitat from Yakutat Bay to Cape Fairweather, by Migratory Waterfowl and Seabirds	1980	126,375
RU-592	Alaska	Summer Distribution and Numbers on Fin, Humpback and Gray Whales in the Gulf of Alaska	1980	606,000
RU-593	Alaska	Feeding Ecology of the Gray Whale in the Northern Bering Sea	1981	274,301
RU-595	Alaska	Microbia Processes as Related to Transport in the North Aleutian Shelf and St. George Lease Areas	1980	230,206
RU-598	Alaska	Storm Petrels As Indicators of Environmental Conditions	1982	250,942
RU-601	Alaska	Habitat Requirements and Expected Distribution of Alaska Coral	1980	51,769
RU-602	Alaska	Oil Rig Monitoring and Effects of Drilling Muds	1981	257,514
RU-603	Alaska	Epipelagic Meroplankton, Juvenile and Forage Fish: Distribution and Abundance in Coastal Waters	1980	16,561
RU-605	Alaska	Habitat Use by Gray Whales in Nelson Lagoon	1980	56,754
RU-606	Alaska	Baffin Island Oil Spill Project (BIOS) Environmental Protection Service	1982	1,036,853
RU-607	Alaska	Biodegradation of Aromatic Compounds by High Latitude Phytoplankton	1981	58,830
RU-608	Alaska	Seasonal Population Density Distribution of Copepods, Euphausids, Amphipods and Other Holoplankton on the Kodiak Shelf	1981	240,697
RU-609	Alaska	Population Dynamics of King, Tanner, and Other Decapod Larvae in the Southeastern Bering Sea	1982	313,769

Contract Number	Region	Title	Year	Amount ($)
RU-611	Alaska	Modern Populations, Migrations, Demography, Trophics, and Historical Status of the Pacific Walrus	1982	1,103,676
RU-612	Alaska	Biological Investigations of Belukha Whales in the Coastal Waters of Northern Alaska	1982	629,328
RU-613	Alaska	Investigations of Marine Mammals in the Coastal Zone of Western Alaska During Summer and Autumn	1981	320,509
RU-615	Alaska	Hydrocarbon Bioaccumulation and Histopathological and Biochemical Responses in Two Species of Marine Bivalve Molluscs (BIOS)	1981	194,278
RU-618	Alaska	Fish Resources of the Nearshore: Information Review and Field Program Design	1981	58,830
RU-619	Alaska	The Nature and Biological Effects of Weathered Petroleum	1982	342,130
RU-620	Alaska	Lethal and Sublethal Effects of Petroleum Contamination on Post-Larval Stages of King Crabs	1982	215,722
RU-622	Alaska	Aerial Surveys of Endangered Whales in the Southern Bering Sea and Western Gulf of Alaska	1983	1,099,157
RU-623	Alaska	Ecological Characterization of Shallow Subtidal Habitats in the North Aleutian Shelf	1982	216,271
RU-624	Alaska	Feeding Ecology of Juvenile King and Tanner Crabs in the Southeastern Bering Sea	1982	287,361
RU-625	Alaska	Endangered Whale and Pinniped Surveys in the Navarin Basin	1983	1,380,335
RU-626	Alaska	Feeding Ecology and Habitat Dependence of the Gray Whales in the Chirikov Basin, Bering Sea, Alaska	1982	504,251
RU-628	Alaska	Population Estimates and Temporal Trends of Pribilof Island Seabirds	1982	9,983
RU-629	Alaska	Effects of Man-Made Waterborne Noise on Behavior of Belukha Whales	1982	277,926
RU-630	Alaska	Geophysical and Biological Reconnaissance of Rock Habitats in Eastern Camden Bay, Beaufort Sea	1982	28,088
RU-631	Alaska	Nearshore Fish Surveys in the Western Beaufort Sea	1982	34,108
RU-632	Alaska	Environmental Characterization and Biological Use of Lagoons in the Eastern Beaufort Sea	1982	276,390
RU-634	Alaska	Biogenic Sedimentary Features of the Northern Bering Sea	1982	65,678
RU-635	Alaska	Fish Distribution and Use of Nearshore Waters in the Northeastern Chukchi Sea	1983	337,500

Contract Number	Region	Title	Year	Amount ($)
RU-636	Alaska	Direct Effects of Acoustic Disturbance Sources on Ringed Seal Reproductive Behavior, Vocalization, and Communication	1983	469,800
RU-638	Alaska	Pribilof Island Crab Investigations	1983	367,500
RU-639	Alaska	Distribution of Red King Crab Larvae and Juveniles Along the North Aleutian Shelf	1983	198,030
RU-641	Alaska	Environmental Characterization and Biological Utilization of Peard Bay	1983	1,397,302
RU-643	Alaska	Simulation Modeling of the Effects of Acute Oil Spills on Commercially Important Fisheries Resources in the Bering Sea	1983	715,500
RU-644	Alaska	Chukchi Sea Coastal Studies: Coastal Geomorphology, Environmental Sensitivity, and Persistence of Spilled Oil	1983	260,800
RU-645	Alaska	Environmental Characterization of the North Aleutian Shelf Nearshore Region	1983	78,880
RU-650	Alaska	Effects of Oiled Sediments on Crab Reproduction	1983	296,800
RU-652	Alaska	Monitoring Program Workshop	1983	60,000
RU-658	Alaska	Environmental Characterization and Biological Utilization of the North Aleutian Shelf and Nearshore Zone	1984	1,938,137
RU-659	Alaska	Seasonal Habitat Use by Inshore Species of Fish North of the Alaska Peninsula	1984	701,924
RU-660	Alaska	Yukon Delta Processes	1984	814,231
RU-661	Alaska	Effects—Herring Reproduction	1984	386,571
RU-662	Alaska	Effects on Food Organisms of Bowhead Whales	1984	71,000
RU-664	Alaska	Oil Weathering in the Presence of Sea Ice	1986	13,513
RU-667	Alaska	Ringed Seal Monitoring and Polar Bear Logistics	1984	872,547
RU-673	Alaska	Aerial Survey of Endangered Cetaceans and other Marine Mammals in the Northwestern Gulf of Alaska and Southern Bering Sea	1985	1,437,905
RU-675	Alaska	Behavioral Responses of Feeding Gray Whales to Industrial Noise	1985	650,864
RU-680	Alaska	Oil-Ice Sediment Interactions During Freezeup and Breakup	1985	1,275,991
RU-681	Alaska	Effects of Petroleum Contaminated Waterways on the Spawning Migration of Pacific Salmon	1986	268,300
RU-682	Alaska	Arctic Fish Habitats and Sensitivities	1986	996,941
RU-685	Alaska	Yukon Delta Processes Study: Biological Studies—Waterfowl Use of Coastal Habitats	1986	267,301
RU-687	Alaska	Chukchi Shelf Benthos	1986	574,604
RU-688	Alaska	Sea Otter Tagging/Tracking Study Along the Alaska Peninsula (False Pass)	1986	174,669
RU-689	Alaska	Marine Birds and Mammals of the Unimak Pass Area	1986	625,894

Contract Number	Region	Title	Year	Amount ($)
RU-690	Alaska	Hope Basin Ecosystem Study	1986	899,551
RU-692	Alaska	Marine Mammal Tissue	1987	223,978
RU-693	Alaska	Coastal Fisheries Oceanography of the Southern Bering Sea and North Aleutian Basin	1987	508,822
RU-694	Alaska	Genetic Stock Identification of Bristol Bay, Alaska Salmon Stock	1987	767,901
RU-695	Alaska	Coastal Fisheries Oceanography of the Southern Bering Sea and North Aleutian Basin—Bering Sea Herring	1988	6,319
RU-701	Alaska	Effects on Amphipods	1987	29,224
RU-702	Alaska	Effects of Petroleum Contaminated Waterways of the Spawning Migration of Pacific Salmon (Phase II)	1988	574,370
RU-703	Alaska	Petroleum Seeps	1987	95,688
RU-707	Alaska	Environmental Characterization and Biological Utilization of Kasegaluk Lagoon	1988	481,481
10244	Atlantic	Effects of Natural Disturbances on Live Bottom Communities	1985	9,995
14624	Atlantic	Aerial Surveys of Right Whales in the Great South Channel—Spring 1987	87	9,600
14669	Atlantic	South Channel Ocean Productivity Experiment (SCOPEX)—Year 1	1987	200,000
17199	Atlantic	Aerial Survey of Right Whales in the Great South Channel During Spring 1988 to Supplement First Year SCOPEX Study	1988	9,938
17203	Atlantic	South Channel Ocean Productivity Experiment (SCOPEX)—Year 2	1988	200,000
29125	Atlantic	Middle Atlantic Chemical and Biological Benchmark Studies—First Year	1975	1,873,138
29129	Atlantic	Middle Atlantic Chemical and Biological Benchmark Studies—Second Year	1976	3,629,823
29130	Atlantic	South Atlantic OCS Benchmark Study FY 1977	1977	4,055,342
29135	Atlantic	A Benthic Recolonization Study in the Mid-Atlantic Region	1978	560,712
29163	Atlantic	Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic OCS	1978	3,704,867
29164	Atlantic	The North and Mid-Atlantic Canyons Assessment Study	1978	612,180
29165	Atlantic	Study of Crude Oil Effects on Developmental Stages of the American Lobster	1979	119,848
29168	Atlantic	South Atlantic OCS Area Living Marine Resources Study	1979	739,204
29169	Atlantic	Study of the Effects of Oil on Marine Mammals	1979	2,018,457
29172	Atlantic on Cetaceans	OCS Oil and Gas Operations: Possible Effects	1980	393,600

Contract Number	Region	Title	Year	Amount ($)
29181	Atlantic	North Atlantic OCS Area Study of the Economic Cost from Oil Spills to Commercial Fishing	1980	954,068
29185	Atlantic	South Atlantic OCS Area Living Marine Resources Study, 2nd Year	1981	1,420,379
29189	Atlantic	North Carolina Fisheries and Environmental Data Search and Synthesis Study	1981	169,730
29190	Atlantic	Analysis of Historical Benthic Infaunal Samples from Georges Bank	1981	100,706
29192	Atlantic	Georges Bank Monitoring Program: Benthic Infauna	1982	3,998,016
29194	Atlantic	The Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments	1982	324,847
29198	Atlantic	Analysis of Hydrocarbons in Bottom Sediments and Analysis of Hydrocarbons and Trace Metals in Benthic Fauna from Georges Bank	1982	103,941
30001	Atlantic	Georges Bank Monitoring Program: Analysis of Hydrocarbons in Bottom Sediments and Hydrocarbons and Trace Metals in Benthic Fauna	1983	292,021
30025	Atlantic	Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments During the Second Year Monitoring Period	1983	317,587
30063	Atlantic	Study of the Effects of Oil on Marine Turtles	1983	552,135
30064	Atlantic	Biological Processes on the U.S. Atlantic Continental Slope and Rise: Part A, and Studies of the North and Mid-Atlantic Slope and Rise: Part B	1983	7,780,235
30153	Atlantic	Georges Bank Monitoring Program: Analysis of Trace Metals in Bottom Sediments During the Third Year Monitoring Period	1984	263,824
30197	Atlantic	Analysis of Trace Metals in Bottom Sediments in Support of Deepwater Biological Processes Studies on the U.S. Atlantic Continental Slope and Rise	1984	372,385
30293	Atlantic	Study of the Effects of Oil on Marine Mammals (Synthesis of Available Information)	1986	221,857
30336	Atlantic	Synthesis of Knowledge of the Potential Outer Continental Shelf Impacts from Oil and Gas Activities on Fisheries	1986	533,747
30362	Atlantic	Synthesis of Information of the Effects of Noise on Marine Mammals and Production of a Manuscript	1987	154,861
30369	Atlantic	Workshop to Facilitate Efforts to Develop Effective Systems for Tracking Endangered Whales	1987	20,098
CT5-12	Atlantic	Effects of the Tamano Spill on the Marine Environment	1975	28,000

Contract Number	Region	Title	Year	Amount ($)
CT6-51	Atlantic	New England Outer Continental Shelf Environmental Benchmark Study	1976	4,302,416
CT8-25	Atlantic	South Atlantic Hard Bottom Study	1978	235,968
IA7-35	Atlantic	NMFS Middle Atlantic Baseline Studies	1977	550,000
P0138	Atlantic	Modification to A Summary of Environmental Information of U.S. Atlantic Slope and Rise	1984	10,500
14549	Gulf of Mexico	Analysis of Dive Logs for Turtle Observation Data	1987	13,595
14943	Gulf of Mexico	Florida Keys Drilling Study	1987	25,000
14945	Gulf of Mexico	Sponsorship of Conference Session on the Ecology of the Gulf of Mexico (American Society of Zoologists)	1987	15,000
17447	Gulf of Mexico	Diving Investigation at Old Drilling Sites Near the Florida Keys Area	1988	105,000
29000	Gulf of Mexico	MAFLA Environmental Monitoring Program, FY 1975	1975	3,872,317
29005	Gulf of Mexico	Ecological Investigations of Petroleum Production Platforms in Central Gulf of Mexico	1978	2,186,738
29006	Gulf of Mexico	Eastern Gulf of Mexico Marine Habitat Mapping Study	1978	373,225
29011	Gulf of Mexico	Texas Barrier Islands Ecological Characterization	1979	827,270
29028	Gulf of Mexico	Southwest Florida Shelf Remote Sensing Study (Marine Productivity and Hydrography)	1982	98,000
29029	Gulf of Mexico	Distribution and Abundance of Endangered and Vulnerable Mammals, Birds, and Turtles, FY 1981	1981	500,000
29036	Gulf of Mexico	Southwest Florida Shelf Regional Biological Communities Survey	1982	845,500
29038	Gulf of Mexico	Data Tape Reformatting Project	1982	49,844
29041	Gulf of Mexico	Eastern Gulf of Mexico OCS Benchmark Study, FY 1977	1977	3,783,010
29085	Gulf of Mexico	Ecological Characterization of the Mississippi Delta Plain Region	1978	892,250
29089	Gulf of Mexico	Marine Birds, Mammals, Turtles, and Endangered Manatee—South Atlantic and Gulf of Mexico Pilot Study	1979	245,673
29091	Gulf of Mexico	Gulf of Mexico Polychaeta Taxonomy Standardization Study	1979	257,602
29096	Gulf of Mexico	Gulf of Mexico and South Atlantic OCS Study on the Distribution and Abundance of Endangered and Vulnerable Mammals, Birds, and Turtles, FY 1980	1980	494,870
29103	Gulf of Mexico	*IXTOC* Oil Spill Damage Assessment Study	1980	555,926
29106	Gulf of Mexico	Ecological Communities of OCS Slope and Adjacent Regimes of Northern Gulf of Mexico	1981	213,319

Contract Number	Region	Title	Year	Amount ($)
29118	Gulf of Mexico	Distribution and Abundance of Endangered and Vulnerable Mammals, Birds, and Turtles	1982	100,000
29124	Gulf of Mexico	South Texas OCS Baseline Study, Biology and Chemistry, FY 1975	1975	726,818
29126	Gulf of Mexico	South Texas OCS Monitoring Study, Biology and Chemistry, FY 1976	1976	2,177,999
29127	Gulf of Mexico	South Texas OCS Topographic Features Study, FY 1976	1976	638,214
29131	Gulf of Mexico	South Texas OCS Baseline Monitoring: Biology and Chemistry, FY 1977	1977	2,307,225
29132	Gulf of Mexico	Northwestern Gulf of Mexico Topographic Features Study, FY 1977	1977	744,361
29134	Gulf of Mexico	South Atlantic and Gulf of Mexico Marine Birds Literature Synthesis and Analysis	1978	190,000
29136	Gulf of Mexico	Gulf of Mexico Topographic Features Study	1978	2,891,344
29137	Gulf of Mexico	South Texas OCS Three Year Data Synthesis Study	1978	501,694
29139	Gulf of Mexico	Gulf of Mexico Effects of OCS Oil Gas Activities on Reef Fish	1979	395,822
29140	Gulf of Mexico	Northern Gulf of Mexico Topographic Feature Study	1980	1,398,690
29142	Gulf of Mexico	Southwest Florida Shelf Ecosystem Study, Year I	1980	1338,285
29144	Gulf of Mexico	Southwest Florida Shelf Hydrographic Study, Year II	1981	1,866,916
29145	Gulf of Mexico	Northern Gulf of Mexico Topographic Features Data Synthesis Study	1981	570,965
30036	Gulf of Mexico	Southwest Florida Shelf Coastal Ecological Characterization (Continuation of 29099)	1980	1,090,973
30037	Gulf of Mexico	Northeastern Gulf of Mexico Coastal Ecological Characterization (Continuation of 29095)	1980	1,185,000
30046	Gulf of Mexico	Northern Gulf of Mexico Continental Slope Study	1983	1,136,128
30048	Gulf of Mexico	Tuscaloosa Trend Study Regional Data Search and Synthesis	1983	285,475
30070	Gulf of Mexico	Environmental and Geologic Atlas of the Texas Coastal Zone	1983	150,000
30071	Gulf of Mexico	Southwest Florida Shelf Benthic Communities Study	1983	808,643
30188	Gulf of Mexico	Florida Big Bend Sea Grass Habitat Study	1984	386,998
30201	Gulf of Mexico	Gulf of Mexico Coastal Ecological Analyses	1984	283,000
30211	Gulf of Mexico	Southwest Florida Shelf Ecosystem Study—Year 2	1984	992,137
30212	Gulf of Mexico	Northern Gulf of Mexico Continental Slope Study—Years 2, 3, and 4	1984	2,543,000
30252	Gulf of Mexico	Outer Continental Shelf Development and Potential Coastal Habitat Alteration	1985	1,389,699

Contract Number	Region	Title	Year	Amount ($)
30276	Gulf of Mexico	Southwest Florida Shelf Ecosystem Study Data Synthesis	1985	378,873
30325	Gulf of Mexico	Impacts of OCS Activities on Sensitive Coastal Habitats	1986	444,481
30346	Gulf of Mexico	Mississippi-Alabama Marine Ecosystem Study	1987	2,471,266
30351	Gulf of Mexico	Coastal and Offshore Environmental Analysis, FY 1987	1987	670,000
30380	Gulf of Mexico	Offshore Texas and Louisiana Marine Ecosystem Data Synthesis	1987	149,972
30383	Gulf of Mexico	Southwest Florida Nearshore Benthic Habitat Study	1987	418,218
30393	Gulf of Mexico	Long-Term Assessment of the Oil Spill at Bahia Las Minas, Panama	1987	1,211,066
30398	Gulf of Mexico	Lethal and Sublethal Effects of Underwater Explosions to Marine Turtles	1987	555,038
30452	Gulf of Mexico	Long-Term Monitoring at the East and West Flower Garden Banks	1988	348,896
30454	Gulf of Mexico	Fates and Effects of Nearshore Discharges of OCS Produced Waters	1988	607,575
30470	Gulf of Mexico	Long-Term Chronic Effects—University Initiative	1989	500,000
CT4-11	Gulf of Mexico	MAFLA OCS Baseline Study, FY 1974	1974	961,278
CT4-13	Gulf of Mexico	Hydrocarbons Quality Control Analyses MAFLA Study, FY 1974	1974	291,305
CT4-16	Gulf of Mexico	MAFLA OCS Hydrographic Study	1974	174,040
CT5-04	Gulf of Mexico	South Texas Topographic Features Study, FY 1975	1975	465,450
CT5-27	Gulf of Mexico	MAFLA OCS Multivariate Analysis of Water Column Data	1975	22,063
CT5-43	Gulf of Mexico	MAFLA OCS Analysis of Hydrocarbons in Epifauna	1975	9,216
CT5-49	Gulf of Mexico	Trace Metals Quality Control Analyses (MAFLA II), South Texas I	1975	110,000
CT7-28	Gulf of Mexico	Eastern Gulf of Mexico OCS Ichthyoplankton Study, FY 1977	1977	88,851
IA5-19	Gulf of Mexico	South Texas OCS Baseline Study, Plankton, Fisheries, and Physical Oceanography, FY 1975	1975	547,700
IA7-03	Gulf of Mexico	South Texas OCS Fisheries Investigation Study (See IA7-21)	1977	285,468
IA7-21	Gulf of Mexico	South Texas OCS Fishing Investigation Study (See IA7-03)	1977	158,662
IA8-27	Gulf of Mexico	Mapping of Seagrasses by Remote Sensing in the Eastern Gulf of Mexico	1978	5,000
MU5-20	Gulf of Mexico	South Texas OCS Baseline Study, Geology, FY 1975	1975	567,946

Contract Number	Region	Title	Year	Amount ($)
P0950	Gulf of Mexico	Publications of Scientific Journal Article on	1984	1,056 Flower Garden Banks
10396	Pacific	Atlas of Fish Larvae of California Current System	1989	54,600
10576	Pacific	Study of Marbled Murrelet in California	1989	41,500
10683	Pacific	Monitoring of Olympic National Park Beaches to Determine Fate and Effects of Spilled Bunker C Fuel Oil	1989	276,810
14257	Pacific	Diving Patterns of Free-Swimming Northern Elephant Seals (Co-funding of study with National Science Foundation)	1987	20,000
17213	Pacific	Effects of Seismic Energy Release on Dungeness Crab Larvae	1988	70,000
29010	Pacific	Ecological Characterization of Central and Northern California Coastal Region	1979	697,300
29079	Pacific	Southern California Bight Baseline, Year I	1975	3,930,264
29080	Pacific	Southern California Bight Intertidal Baseline Survey, Year II	1976	6,237,532
29082	Pacific	Southern California Marine Mammal and Seabird Survey, Year II	1977	971,104
29083	Pacific	Southern California Bight Intertidal Baseline Survey, Year III	1977	2,137,858
29087	Pacific	Biological and Geological Reconnaissance and Characterization Survey of the Tanner and Cortes Banks	1978	658,166
29088	Pacific	Seabird Nesting and Seasonal Use: Central and Northern California	1979	147,492
29090	Pacific	Central and Northern California Marine Mammal and Seabird Study	1979	3,714,914
29102	Pacific	California Seabird Oil Spill Behavior Study	1980	496,294
29104	Pacific	Oil Spill Vulnerability (Risk) Assessment of Marine and Coastal Habitats in Central and Northern California	1980	487,464
29105	Pacific	California Commercial and Sports Fish Oil Toxicity Study and Monitoring Workshop	1980	1,063,133
29112	Pacific	Seabird Oil Toxicity Study	1981	1,012,922
29115	Pacific	Southern California Marine Mammal/ Seabird Risk Analysis	1982	184,356
29122	Pacific	Evaluation of Effluent Dispersion and Fate Models for OCS Platforms	1982	56,868
30005	Pacific	Observations of Sea Otter Behavior	1983	31,546
30023	Pacific	Synthesis of Available Population Information on California Sea Otters	1983	

Contract Number	Region	Title	Year	Amount ($)
30032	Pacific	Assessment of Long-Term Changes in the Biological Communities. Phase I. Benthic Reconnaissance of Santa Barbara Channel/Santa Maria Basin	1983	1,508,565
30033	Pacific	Population Status of California Sea Otters/ Simulation Modeling of the Effects of Oil Spills on Population Dynamics of Key Marine Mammal Species	1983	1,187,090
30056	Pacific	Assessment of the Long-Term Fate and Effective Methods of Mitigation of California OCS Platform Particulate Discharges	1983	219,537
30057	Pacific	Successional/Seasonal Variation of the Central and Northern California Rocky Intertidal Communities as Related to Natural and Man-Induced Disturbances	1983	1,495,000
30157	Pacific	Sea Otter Oil Spill Mitigation Study	1984	473,247
30159	Pacific	Adaptation of Marine Organisms to Chronic Hydrocarbon Exposure	1984	961,738
30183	Pacific	Northern California Seabird Ecology Study	1984	514,323
30224	Pacific	Completion of Southern California Marine Mammal and Seabird Risk Analysis	1984	58,979
30256	Pacific	Sea Otter Oil Spill Avoidance Study	1985	551,240
30262	Pacific	Monitoring: Assessment of Long-Term Changes in Biological Communities	1986	7,590,000
30273	Pacific	Study of the Effects of Offshore Geophysical Acoustic Survey Operations on Important Commercial Fisheries in California	1985	509,885
30294	Pacific	California OCS Fisheries Database	1985	537,929
30306	Pacific	Gray Whale Monitoring Study	1986	188,195
30341	Pacific	Ecology of the Southern California Bight: A Synthesis and Interpretation	1987	339,865
30388	Pacific	Biological Reconnaissance of Selected Benthic Habitats Within Three California Planning Areas	1987	934,168
30426	Pacific	Oregon and Washington Marine Mammal and Seabird Study	1988	1,484,586
30429	Pacific	An Evaluation of Spawning and Recruitment Patterns of Fishes off Northern California, Oregon, and Washington	1988	288,260
30445	Pacific	Fish Assemblages of Rocky Banks of the Pacific Northwest	1988	300,000
30451	Pacific	Biological Impacts of Translocated Sea Otters	1988	90,652
30456	Pacific	Seabird Nesting for Central and Northern California Region and Preparation of the Catalog of California Seabird Colonies	1988	180,000

Contract Number	Region	Title	Year	Amount ($)
30459	Pacific	Washington, Oregon, and California OCS Fisheries Database	1988	448,509
30471	Pacific	Long-Term Chronic Effects—University Initiative	1989	500,000
CT5-28	Pacific	Southern California Marine Mammal and Seabird Survey, Year I	1975	652,000
CT6-15	Pacific	Summary and Analysis of Environmental Information of the Oregon and Washington Coastal Zone and Offshore Areas	1976	157,184
CT6-26	Pacific	Southern California Marine Mammal and Seabird Survey, Year II	1976	1,028,951
10410	Washington	Publication of IWC Right Whale Workshop Proceedings	1985	2,000
10548	Washington	Reactivation of Registry of Marine Pathology	1989	5,000
12366	Washington	Study of Right Whales in the South Atlantic, Spring 1986	1986	5,000
12432	Washington	Conference on Fish Pathology Nomenclature	1986	10,000
12504	Washington	Right Whale Survey—North Atlantic	1986	4,950
14182	Washington	National Bureau of Standards Project to Develop Standard Reference Materials for Marine Sediments and Tissues of Marine Organisms	1987	40,000
14562	Washington	Beringian Marine Mammals as Indicators	1987	7,430
14638	Washington	Chemrawn IV Modern Chemistry and Chemical Technology Applied to the Oceans and Its Resources	1987	10,000
14666	Washington	Reimbursement of a Satellite-Monitored Radio Transmitter (Argos PTT) from Telonics, Inc.	1987	3,000
14863	Washington	1988 International Drilling Waste Conference	1987	5,000
14945	Washington	Ninth Biennial International Research Conference	1987	10,000
16870	Washington	Right Whale Recovery Project—Video Tape	1988	1,000
16893	Washington	Right Whale Study in South Atlantic, Spring 1988	1988	3,500
17041	Washington	Diving Patterns of Free-Swimming Northern Elephant Seals		25,000
17578	Washington	Tagging and Tracking a Platform Sea Turtle	1988	8,800
29022	Washington	Partial Support of NAS Workshop to Update the 1975 Report on Petroleum in the Marine Environment	1981	20,000
29063	Washington	Review and Assessment of Fates and Effects of Drilling Muds and Cuttings in the Marine Environment	1981	116,500
29075	Washington	NAS Oceans Sciences Board Research Support	1982	30,000
29092	Washington	Curating Biological Specimens from OCS Environmental Studies	1979	1,396,070
29128	Washington	Analyze Marine Samples from MAFLA, Southern California, South Texas, North Atlantic, and South Atlantic OCS	1976	939,503

Contract Number	Region	Title	Year	Amount ($)
29146	Washington	Publication of Papers on the Macrobenthos of the Middle Atlantic Continental Shelf—Task 1	1982	13,332
29147	Washington	Analysis and Publication of Three Manuscripts for Oil Spill Programs	1982	25,312
29148	Washington	Analysis and Publication of Significant Findings from Information Collected for the OCS Studies Program—Hydrocarbon Chemistry	1982	19,571
29149	Washington	Publication of Papers on Ecological Characterization of Macrofaunal Communities of the Eastern Gulf of Mexico	1982	9,894
29150	Washington	Publication of Papers on Remote Censusing of Fish Assemblages Associated with Oil and Gas Production Structures and Natural Hard Bottoms in the Gulf of Mexico	1982	10,672
29151	Washington	Publication of Papers on Benthic Biota and Fish Assemblages Associated with Oil and Gas Production Structures and Natural Hard Bottoms in the Northern Gulf of Mexico	1982	10,971
29152	Washington	Analysis and Publication of Three Manuscripts on Behavior of Bowhead Whales	1982	40,000
29153	Washington	Publication of Paper on Ecology of Macrobenthos of the North Central Gulf of Mexico	1982	15,049
29154	Washington	Publication of Paper on Quantification of Potential Oil Spill Impacts on Georges Bank Commercial Fisheries	1982	15,640
29155	Washington	Analysis and Publication of Significant Findings from Information Collected for the OCS Studies Program—Task 3	1982	20,744
29156	Washington	OCS Data Synthesis and Publication of a Paper on the Macroinfaunal Benthos of the U.S. South Atlantic Bight	1982	18,944
29157	Washington	OCS Data Synthesis and Publication of a Paper on the Deepwater Biological Communities of Two Offshore Southern California Banks	1982	19,621
30016	Washington	Distributions of Beringian Sea Marine Mammals Related to Oceanographic Characteristics (Continued under purchase order to Dr. C. Ray)	1983	9,321
30024	Washington	Second Adaptive Environmental Assessment Workshop on Drilling Muds	1983	15,000
30089	Washington	Analysis, Interpretation, and Write-up of Bowhead Data from Prior LGL Work	1983	4,000
30090	Washington	A Quantitative Description and Analysis of High-Use Cetacean Habitats on the Northeast U.S. Continental Shelf	1983	19,361
30091	Washington	Distributional Biology of the Right Whale from Cape Hatteras to Nova Scotia	1983	19,303

Contract Number	Region	Title	Year	Amount ($)
30092	Washington	Common Dolphin (*Delphinus delphis*) Distribution in the Southern California Bight: Statistical Modeling of Aerial Transect Data	1983	11,627
30093	Washington	California Sea Lion (*Zalophus californianus*) Distribution in the Southern California Bight Waters: Statistical Modeling of Aerial and Ship Transect Data	1983	11,627
30094	Washington	Analysis of Data from the MAFLA Rig Monitoring Study and Publication of Scientific Article	1983	14,470
30095	Washington	Analysis of Data from the Bureau of Land Management STOCS Study and Publication of Scientific Articles	1983	19,457
30096	Washington	Distribution of Trace Metals in Marine Sediments	1983	26,464
30097	Washington	The Occurrence of Polychaete Mats (*Phylochaetopterus socialis*) off South Carolina	1983	6,101
30098	Washington	Population Dynamics of Benthic Macrofauna on the Southwest Beaufort Sea	1983	15,830
30099	Washington	Analysis of Macrobenthic Data Collected During the Central Gulf OCS Studies	1983	23,300
30100	Washington	Biogeography of Intertidal Communities Along the California Coast	1983	12,698
30101	Washington	Aspects of the Biofouling Community off Petroleum Platforms in the Central Gulf of Mexico	1983	9,408
30102	Washington	Publication of Scientific Manuscript—Comparison of Epifauna in North Atlantic Canyons	1983	17,735
30103	Washington	Analysis of MAFLA Macroinfauna Data and Associated Databases and Publication of Significant Scientific Findings in Refereed Scientific Journal	1983	18,985
30114	Washington	Relative Marine Productivity of the OCS Planning Areas	1983	764,170
30268	Washington	Implementation of Long-Term Effects Program	1985	311,152
30355	Washington	Short-Term Assessment of the Oil Spill at Bahia Las Minas, Panama	1987	231,485
CTO-23	Washington	Effects of Whale Monitoring System Attachment Devices on Whale Tissue	1980	74,512
CT3-0198	Washington	Socioeconomic and Environmental Factors Relating to the Area Adjacent to and Including the OCS from Sandy Hook, New Jersey to the Bay of Fundy	1973	201,824
CT3-09	Washington	Environmental and Socioeconomic Factors Relating to the Area Adjacent to and Including the OCS from Cook Inlet to Unimak Island, Alaska	1973	69,514

Contract Number	Region	Title	Year	Amount ($)
CT3-10	Washington	Socioeconomic Factors Relating to the Area Adjacent to and Including the OCS from Brownsville, TX to the Point 24 N., 81 W. (Gulf of Mexico)	1973	28,404
CT4-12	Washington	Marine Benthic Fauna Including Demersal Fishes on the OCS from De Soto Canyon, LA to Brownsville, TX	1974	52,830
CT6-33	Washington	Symposium: Sources, Effects, and Sinks of Hydrocarbons in the Aquatic Environment	1976	10,000
CT6-35	Washington	Workshop: Hydrocarbon Quality Control	1976	2,519
CT6-58	Washington	Operation and Maintenance of a Lobster Toxicity Laboratory Module	1976	5,400
CT7-24	Washington	Effects of Crude Oil on Development Stages of American Lobsters	1977	312,000
CT8-26	Washington	Hydrocarbon Quality Control Analyses, FY 1978	1978	37,348
IA5-36	Washington	Film Processing in Support of Study CT5-28	1975	43,000
IA6-34	Washington	Distribution and Fates of Biogenic and Petroleum Derived Substances from Sediments	1976	481,325
IA7-09	Washington	Environmental Impacts of the *Argo Merchant* Oil Spill	1977	170,000
IA7-20	Washington	A Study of the Biogeochemistry of Petroleum Components at the Sediment-Water Interface	1977	307,960
MUO-37	Washington	Assessments of the Effects of Oil and Gas Development in the Offshore Texas and Louisiana Marine Ecosystems	1980	9,000
P0231	Washington	Pilot Study to Determine Feasibility of Using Lignosulfonates as Tracers of Drilling Muds in Marine Sediments	1984	24,580