


"Addressing the Effects of Human-Generated Sound on Marine Life:
An Integrated Research Plan for U.S. Federal Agencies"

A Report of the Joint Subcommittee on Ocean Science & Technology (JSOST)

~ INTERAGENCY TASK FORCE ON ANTHROPOGENIC SOUND AND THE MARINE ENVIRONMENT ~

Contributing Federal Agencies (in alphabetical order):

Marine Mammal Commission (MMC)
Minerals Management Service (MMS)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation (NSF)
U.S. Army Corps of Engineers (ACE)
U.S. Coast Guard (USCG)
U.S. Department of Defense, U.S. Navy (USN)
U.S. Department of Energy (DOE)
U.S. Department of State (DOS)
U.S. Fish and Wildlife Service (FWS)

This document should be cited as follows:

Southall, B., Berkson, J., Bowen, D., Brake, R., Eckman, J., Field, J., Gisiner, R., Gregerson, S., Lang, W., Lewandoski, J., Wilson, J., and Winokur, R. 2009. Addressing the Effects of Human-Generated Sound on Marine Life: An Integrated Research Plan for U.S. federal agencies. Interagency Task Force on Anthropogenic Sound and the Marine Environment of the Joint Subcommittee on Ocean Science and Technology. Washington, DC.

Acknowledgements

We appreciate and acknowledge the many scientists and managers from participating federal agencies that contributed to this report

Cover page photo credits (from left to right)
(1) Sperm whale beginning a dive in Mississippi Canyon Block 127 in the Gulf on the 2002 S-tag cruise (photo credit: Christoph Richter, Texas A&M University-Galveston).

(2) Acoustic and behavioral monitoring tag being applied to a pilot whale in Hawai'i by Duke University researcher Doug Nowacek; NOAA's research vessel Oscar Elton Sette is visible in the background (photo credit: NOAA/NMFS Pacific Islands Fisheries Science Center).

(3) Harbor seal participating in behavioral hearing experiments in a specialized anechoic testing chamber at Long Marine Laboratory, University of California, Santa Cruz, CA (photo credit: Brandon Southall, NOAA).

(4) Harbor porpoise (photo credit: Ari Friedlaender, Duke University)

Council on Environmental Quality
Office of Science and Technology Policy
Executive Office of the President
January 13, 2009

Dear partners and friends in the ocean and coastal community:

We are pleased to present this report, ***Addressing the Effects of Human-Generated Sound on Marine Life: An Integrated Research Plan for U.S. Federal Agencies***. This report was developed in response to an Interagency Committee on Ocean Science and Resource Management Integration request for a focused, coordinated Federal science and technology plan from the National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology (JSOST). The JSOST's Interagency Task Force on Anthropogenic Sound and the Marine Environment prepared this report.

Whether and how human-generated sounds in the ocean affect marine life has become an issue of increasing awareness, within scientific and regulatory circles as well as among the general public. Many activities vital to our society, including the actions of many Federal agencies, introduce sound into the marine environment. Consequently, there is much interest and effort involved in understanding associated environmental impacts and, where appropriate and practical, developing ways of minimizing them. A number of Federal agencies are actively engaged in advancing the science and technologies needed to address these challenging issues.

This report provides an explicit interagency roadmap for the next decade to focus and prioritize research efforts addressing this issue. It summarizes collective research efforts by Federal agencies in several key areas and includes a number of specific and prioritized research recommendations regarding future efforts, with particular emphasis on interagency collaboration. Finally, it summarizes some general coordinating actions and means of increasing the transparency and public recognition of ongoing interagency efforts in this field. The findings indicate that many of the challenging scientific, regulatory, and legal issues regarding underwater sound can be addressed with focused, prioritized, and sustained effort coordinated among the Federal agencies. We hope it will be useful to a broad range of interested parties.

Sincerely,

James L. Connaughton
Chair, Committee on Ocean Policy
Chair, Council on Environmental Quality

John H. Marburger III
Director
Office of Science and Technology Policy

Joint Subcommittee on Ocean Science and Technology (JSOST)

Dr. Tim Killeen, NSF, Co-Chair
Dr. Richard Spinrad, DOC/NOAA, Co-Chair
Dr. Dan Walker, OSTP, Co-Chair

Arctic Research Commission
John Farrell

Department of Agriculture
Louie Tupas

Department of Commerce
National Oceanic and Atmospheric Administration
Richard Spinrad
Steve Murawski
Marie Colton

Department of Defense
U.S. Army Corps of Engineers
Charles Chesnutt
Joan Pope

Department of Defense
Office of Naval Research
Linwood Vincent
James Eckman

Department of Energy
Office of Science
Julie Carruthers
James Ahlgrimm

Department of Health and Human Services
Centers for Disease Control and Prevention
Lorraine Backer
G. David Williamson

Department of Health and Human Services
Food and Drug Administration
Robert Dickey
William Jones

Department of Health and Human Services
National Institutes of Health
Allen Dearry

Department of Homeland Security
U.S. Coast Guard
Jonathan Berkson

Department of the Interior
Kameran Onley
Tim Petty

Department of the Interior
Minerals Management Service
James Kendall
Walter Johnson

Department of the Interior
United States Geological Survey
Linda Gunderson
John Haines

Department of Justice
Bradford McLane

Department of State
David Balton
Liz Tirpak

Department of Transportation
Maritime Administration
Richard Corley

U.S. Environmental Protection Agency
George Gray
Steven Hedtke

Executive Office of the President
Council on Environmental Quality
Hardy Pearce

Executive Office of the President
Domestic Policy Council
Paul Skoczylas

Executive Office of the President
Office of Management and Budget
Stuart Levenbach
Kimberly Miller

Executive Office of the President
Office of Science and Technology Policy
Dan Walker

Joint Chiefs of Staff
Robert Winokur
Nadeem Ahmad

National Aeronautics and Space Administration
Jack Kaye
Eric Lindstrom

National Science Foundation
Tim Killeen
Julie Morris

Marine Mammal Commission
Robert Gisiner
Tim Ragen

Smithsonian Institution
Leonard Hirsch

JSOST Interagency Task Force on Anthropogenic Sound and the Marine Environment

Primary Authors

Brandon Southall (Task Force Lead)
National Oceanic and Atmospheric Administration

John Berkson
U.S. Coast Guard

Diane Bowen
U.S. Fish and Wildlife Service

Robin Brake
Office of the Assistant Secretary of the Navy, Environment and Installations

James Eckman
Office of Naval Research

John Field
Department of State

Bob Gisiner
Marine Mammal Commission

Susan Gregerson,
Department of Energy

Bill Lang
National Science Foundation

Jill Lewandoski
Minerals Management Service

Judy Wilson
Minerals Management Service

Robert Winokur
Joint Chiefs of Staff

Additional Contributors

Maggie Hayes
Department of State

Martin Kodis
U.S. Fish and Wildlife Service

John Prydol
Department of Energy

Tim Ragen
Marine Mammal Commission

Amy Scholik-Schlomer
National Oceanic and Atmospheric Administration

Holly Smith
National Science Foundation

Roxanne Nikolaus
National Science Foundation

Joseph Wilson
U.S. Army Corps of Engineers

Augustus Vogel
U.S. Department of Defense, Office of the Oceanographer of the Navy

Table of Contents

Report Overview and Summary

The issue of anthropogenic sound[1] and its possible impacts on the marine environment has created unique challenges for virtually all federal agencies conducting, supporting, or assessing operations in the marine environment. These agencies are charged with regulating, supporting, and/or performing activities in the marine environment vital to our nation's health, economy, and security across a wide scope of sectors. Sound (both intentionally produced as a tool or as a by-product of other activities) is an integral part of the activities of these agencies and of many critical human activities, including vessel operation and navigation, offshore minerals exploration, national defense, and scientific research. Federal agencies are challenged with achieving their mission goals in conducting and/or regulating these critical activities while meeting their mandated responsibilities as environmental stewards for the nation. Continuing to develop a scientific basis for determining potential impacts and the appropriate response is an urgent requirement for federal agencies, if they are to continue to achieve their primary missions for our nation in an environmentally safe manner.

There is considerable scientific uncertainty regarding the nature and magnitude of the actual impacts of anthropogenic sound on the marine environment, as well as the most appropriate and effective mitigation measures where effects have been demonstrated or are likely. Societal benefits from the full spectrum of sound-producing activities should be considered along with, and not overshadowed by, any potential negative impacts of those activities. The goal of federally-supported research in this area

1 Within this report, the term "sound" is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect. "Sounds" include both meaningful signals and "noise" which may have either no particular impact or may have a range of adverse effects. The term "noise" is only used where adverse effects are specifically described, or when referring to specific technical distinctions such as "masking noise" and "ambient noise."

is to obtain mission-critical data that are used in a timely and effective manner to inform policy guidance, develop targeted mitigation measures, and develop and improve regulatory criteria.

How anthropogenic sound may affect marine life is a new field of study. What began as a simple concern that commercial shipping might affect the long-distance calls of whales (Payne and Webb, 1972) has now evolved into a more complex recognition that various anthropogenic acoustic sources have the potential to adversely affect marine life. Additionally, concerns regarding potential impacts are compromising human applications of sound for important scientific, commercial, and military purposes, particularly where scientific data are lacking or ambiguous. These concerns stem from both an increased understanding of the biological importance of sound to most marine vertebrates (particularly marine mammals and many fish) and a growing appreciation of the value of acoustics as a tool for ocean research, energy development, monitoring ocean health, resource management, military activities, and ship operations. How do we as a society reconcile our growing dependence on sound as a tool for studying, using, and conserving the marine environment with a similarly growing understanding of the potential for unintended adverse environmental consequences? How do we balance the potential negative environmental impacts from the incidental introduction of sound with the benefits of ocean-based commerce, national security, research, or transportation? And most important, how do we regulate these

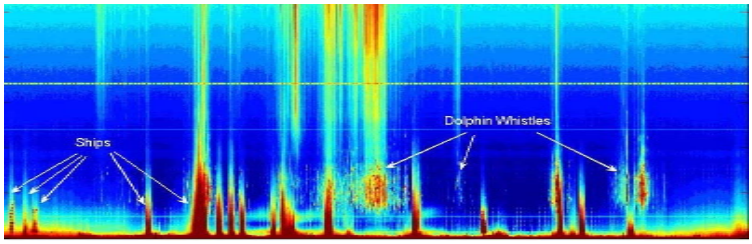


Image courtesy of Dr. John Hildebrand, Scripps Institute of Oceanography

essential human activities in the face of significant scientific uncertainty about adverse effects? Many of these fundamental questions remain to be answered and they clearly require additional scientific data to be adequately addressed.

The most immediate response by U.S. federal agencies has focused on understanding and minimizing the potential adverse effects of their activities, or activities they support or regulate. The current status of science (in terms of exactly what level and types of sound will result in a specific effect) often results in estimates of potential adverse impacts that contain a high degree of uncertainty.

Public perception of threats and scientific analyses of risks may lead to different priorities for acoustic research. There is growing concern by scientific experts in relevant disciplines, that the public and legal focus on a very narrow range of active sources and the predictable agency responses are distorting an appropriate scientific approach to assessing the broader impacts of anthropogenic noise as a global issue (see NRC, 2000; 2003; 2005; Nowacek *et al.*, 2007; Southall *et al.*, 2007). This creates a growing need for both transparency and public and stakeholder outreach as agencies respond to the increasing awareness of sound as an environmental issue.

The laudable aim of minimizing acoustic effects has produced controversy, social tension, and litigation. It has also led to precautionary restrictions, considerable additional costs and delays, not the least of which has been the paradoxical effect of hindering ocean acoustic science essential to understanding not only this issue but also other important environmental issues such as the marine aspects of climate change. These anticipatory restrictions and other precautions imposed through litigative challenges have taken place against a background of considerable uncertainty as to the

nature and extent of impacts from noise exposure. It is this gap, between what should and can be done with scientific confidence and what is currently being done with abundant precaution but demonstrable societal cost, which we seek to reduce through the coordinated federal research strategy depicted here. A summary of key overarching summary points is given below (Box 1).

Box 1 – OVERVIEW OF KEY POINTS

Sound is of vital importance for most marine vertebrates.

Natural and human sounds can have benign (or no) to significant effects on marine life.

Public, media and regulatory attention has focused on known and/or potential adverse impacts of active sonar and seismic systems, but agencies must consider a wider array of sound sources.

Existing data needed to assess and mitigate effects are limited, leading to uncertainty in determining the necessary responses (if any).

Federal research has been largely focused on immediate needs specific to individual agencies.

However, agencies often have common science and technology needs on this issue that could be most quickly and economically met through a coordinated program of effort.

Purpose of Report

As the scope and nature of the issue has expanded, so has the need for increased communication and collaboration across federal agencies[2]. At present, federal agencies have already begun working to develop tools, technologies, and knowledge to provide empirical data on these difficult questions, but these have largely occurred at an agency-specific level. In response, the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI) formed an "Interagency Task Force on Anthropogenic Sound and the Marine Environment" within the Joint Subcommittee on Ocean Science & Technology (JSOST). This Task Force was comprised of federal

2 Brief descriptions of the mandates of involved U.S. federal agencies relative to the issue of marine sound, as well as agency representatives contributing to this report are listed in Appendix 1.

agencies most directly involved in this issue with each individual agency providing a representative to participate and speak for their agency perspective. The Task Force was charged with developing a focused, coordinated science and technology plan of action among federal agencies and reporting on this plan through JSOST to ICOSMRI. Therefore, this report represents an overall, interagency (not individual agency) perspective, as determined through the interactions and deliberations of Task Force members.

The recommendations offered within this report provide a strategic vision for integrating, prioritizing and optimizing the science and technology efforts of U.S. federal agencies on marine anthropogenic sound over the next decade. It is based on lessons learned from inter-agency coordination on ocean science issues generally, as well as coordination on pressing research needs regarding this issue specifically. The intent is to promote and develop better scientific understanding, thereby leading to better documentation of effects, less controversy regarding risks, increased scientific certainty underlying policies and regulatory decisions, and effective mitigation efforts where impacts are known or likely. The report is also intended to improve the combined federal effort by increasing inter-agency coordination, planning, and leveraging resources, while reducing redundancy and disproportionate focus in a few areas.

The report is organized into a general overview (this section) that summarizes the key issues and recommendations of the task force, followed by a list of acronyms, five primary chapters, and three detailed appendices. Throughout the report, completed research and specific recommended research actions are given within five general subject categories: (1) Sound Sources and Acoustic Environment; (2) Baseline Biological

Information (Physiology, Distribution, and Abundance); (3) Effects of Sound (Criteria and Thresholds); (4) Monitoring and Mitigation; and (5) Outreach, Education, and Scientific Peer Review. Chapter 1 states the general issue in greater detail than this general overview and provides a sense of the limits to currently available information. Chapter 2 provides an overview of effort to date by federal agencies. Chapter 3 offers specific recommendations for future effort and sets priorities within specific action areas. Chapter 4 considers the opportunities and obstacles for inter-agency coordination. Chapter 5 draws together both general and specific recommendations for a coordinated federal science and technology response to this issue, acknowledging the pragmatic challenges that are known or expected. Appendix I provides a summary of the roles and responsibilities of the participating federal agencies on the marine sound issue; it also includes a list of the agency representatives that contributed to the preparation of this report. Subsequent appendices are more detailed versions of Chapters 2 and 3, providing additional specific information on the current federal effort (Appendix II) and prioritized recommended future federal research and development (Appendix III).

Task Force Conclusions and Recommendations

The Task Force considered both positive and negative outcomes of anthropogenic sound in the marine environment, both through direct use of acoustics for sensing and communication, and through the noise generated as an unwanted, but often unavoidable, aspect of essential human ocean-related activities (*e.g.*, shipping, marine construction, energy exploration and production). Additionally, we note that the scientific understanding and technologies that are needed to enable the federal government to

respond appropriately will, in some cases, be the same tools and technologies required to better execute federal national security and resource management missions. The full extent of research required to address the environmental consequences of anthropogenic marine sound can seem overwhelming. However, some clear, high-priority actions exist that should be undertaken collaboratively among federal agencies for effective action on this issue, including better understanding of the actual impacts of noise, both acute and cumulative.

Of these, the Task Force has identified both specific research action areas and general coordination recommendations which are of the greatest importance to the federal government. Table 1(below) provides an ordinal ranking of these *highest* priority research action areas, their associated suggested timelines (*i.e.*, short-term vs. long-term), and those agencies most likely to have leading/direct interest and/or secondary level of involvement. Each recommended research action area in Table 1 is subjectively categorized by the overall importance and social relevance of the work ("importance") and the relative level of effort required for significant progress ("effort"): (1) High importance/moderate effort; (2) High importance/high effort; (3) Moderate importance/moderate effort; (4) Moderate importance/high effort. [note: additional details regarding the research action areas specified here are given in Chapter 3 and Appendix III].

Table 1 – Overview of Highest Priority Research Recommendations

Prioritized Recommended Federal Research Action Areas	Short or Long-term?	Relative Importance and Level of Effort *	Agencies Involved (see notes below)	General Subject Area(s) (described in Chapter 2)
(1) Improve ability to identify and understand biologically-significant effects of sound exposure in order to improve effectiveness and efficiency of efforts to mitigate risk.	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1]MMC[2] NSF, USN, MMS	Effects of Sound
(2) Hearing, physiological, behavioral, and effects data (*e.g.*, controlled exposure studies) for key species of concern (baleen whales, beaked whales, Arctic & endangered species).	Ongoing and long-term	**High Importance/ High Effort**	USN[1], NOAA[2], NSF, MMS, MMC	Baseline Biological Information; Effects of Sound
(3) Develop new technologies (*e.g.*, acoustic monitoring) to detect, identify, locate, and track marine mammals, in order to increase the effectiveness of detection and mitigation.	Ongoing and short-term	**High Importance/ Moderate Effort**	USN[1], NOAA[1], MMS, NSF, USCG, ACE, DOT, FWS	Sound Sources and Acoustic Environment; Mitigation and Monitoring
(4) Develop and validate mitigation measures to minimize demonstrated adverse effects from anthropogenic noise.	Short-term and long-term	**High Importance/ High Effort**	NOAA[1], MMC[2], USN, MMS, NSF, FWS, USCG, ACE	Mitigation & Monitoring; Effects of Sound
(5) Support the development, standardization, and integration of online data archives of marine mammal distribution, abundance, and movement for use in assessing potential risk to marine mammals from sound-producing activities.	Ongoing, short, and long-term	**High Importance/ Moderate Effort**	NOAA[1], USN, FWS, MMS, MMC	Baseline Biological Information
(6) Long term biological and ambient noise measurements in high-priority areas (*e.g.*, Arctic, protected areas, commerce hubs).	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1] USN, MMS	Sound Sources and Acoustic Environment
(7) Test/validate mitigating technologies to minimize sound output and/or explore alternatives to sound sources with adverse effects (*e.g.*, alternative sonar waveforms).	Long-term	**High Importance/ High Effort**	USN[1], NSF[1], MMS[1], NOAA, MMC, DOE	Mitigation & Monitoring
(8) Explore need for and effectiveness of time/area closures versus operational mitigation measures.	Ongoing and long-term	**Moderate Importance/ Moderate Effort**	MMS[1], NOAA[2], MMC[2], USN, NSF	Mitigation and Monitoring
(9) Develop and improve noise exposure criteria and policy guidelines based on periodic reviews of best available science to better predict and regulate potential impacts.	Ongoing and long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMC[2], USN, MMS, NSF	Effects of Sound
(10) Standardize data-collection, reporting, and archive requirements of marine mammal observer programs.	Long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMS, NSF, USN, USCG, MMC	Mitigation and Monitoring
(11) Expand/improve distribution, abundance and habitat data for marine species particularly susceptible to anthropogenic sound.	Ongoing and long-term	**Moderate Importance/ High Effort**	NOAA[1], FWS[1], USN, MMC, MMS	Baseline Biological Information

Notes:
[*] note shading corresponds to four relative importance/effort categories; see text for more detailed explanation
[1] denotes agencies with a leading and/or direct interest on each recommended action
[2] denotes agencies with a secondary level of involvement in each recommended action

Many of the research action areas included in these recommendations are to some extent already being investigated or acted upon by some of the participating agencies in this task force. However, our intention is to focus on those action items and research recommendations that are most likely to remain important for the U.S. federal government, now and over the coming decade. Some of these will require prioritization and action by individual agencies; others will need more concerted inter-agency collaboration.

Perhaps the most important outcome of this report, and of the Task Force generally, is the increased coordination, communication, and planning across federal agencies on this important environmental issue. In order to sustain existing collaborations and enhance further coordination, the Task Force felt it was also imperative to identify the *highest* priority coordination action items. The Task Force feels these actions are critical for the successful implementation of this strategic plan and will ultimately maximize the diverse capabilities and perspectives of the federal agencies. These highest priority coordination action items include:

- **Sustained interagency collaboration and coordination, including:**
  - High-level, inter-agency coordination among individuals with sufficient authority to make timely planning and budget recommendations within their respective agencies; and
  - Program-level, inter-agency coordination among agency subject matter experts and program managers to implement directives and provide technical advice to leadership.

- **Enhanced communication and coordination on the marine sound issue with private sector interests and with the governments of other nations to reduce duplication of effort and advance a consistent scientific response.**
- **Continued efforts to streamline research permitting involving acoustic sources.**
- **Development of a biennial forum for information transfer to report on the results of inter-agency research to various stakeholders (*e.g.*, federal and state government agencies, industry, academia, public, educators, media, and environmental groups).**

ACRONYMS USED IN THIS REPORT:

Behavioral Response Study (**BRS**)
Controlled Exposure Experiment (**CEE**)
Discovery of Sound in the Sea (**DOSITS**) [website: www.dosits.org]
Endangered Species Act: (**ESA**)
Environmental Consequences of Underwater Sound (**ECOUS**)
Interagency Committee on Ocean Science and Resource Management Integration: (**ICOSRMI**)
Inter-agency Coordinating Group (**ICG**)
Interagency Task Force on Anthropogenic Sound and the Marine Environment: (**IATF**)
Joint Subcommittee on Ocean Science & Technology: (**JSOST**)
Marine Mammal Commission: (**MMC**)
Marine Mammal Protection Act: (**MMPA**)
Minerals Management Service: (**MMS**)
National Environmental Policy Act: (**NEPA**)
National Oceanic and Atmospheric Administration: (**NOAA**)
National Oceanographic Partnership Program (**NOPP**)
National Research Council: (**NRC**)
National Science Foundation: (**NSF**)
Office of Naval Research (**ONR**)
Passive Acoustic Monitoring (**PAM**)
Permanent Threshold Shift (**PTS**)
Temporary Threshold Shift (**TTS**)
U.S. Army Corps of Engineers: (**ACE**)
U.S. Coast Guard: (**USCG**)
U.S. Department of Defense, U.S. Navy: (**USN**)
U.S. Department of Energy: (**DOE**)
U.S. Department of State: (**DOS**)
U.S. Fish and Wildlife Service: (**FWS**)
U.S. Government: (**USG**)

Chapter 1. Anthropogenic Sound and the Marine Environment: Framing the Issue

Chapter 1 – Key Points
• **Sound is of vital importance for most marine vertebrates.** • **Natural and human sounds can have various effects on marine life, along a continuum from benign (or no) to severe, depending on conditions.** • **Much attention has been on the impacts of active military sonar systems, but federal agencies must also consider the characteristics and purposes of other sound sources.** • **U.S. federal agencies have varied mandates, and thus varied research objectives, but do share overlapping needs in many areas** • **This report represents a synthesis of those shared needs and a strategic vision of collective federal research and development objectives for the coming decade.** • **The coordinated federal research strategy depicted here seeks to reduce the gap between what should and can be done with scientific confidence and what is currently being done in certain cases with abundant precaution but demonstrable societal cost.**

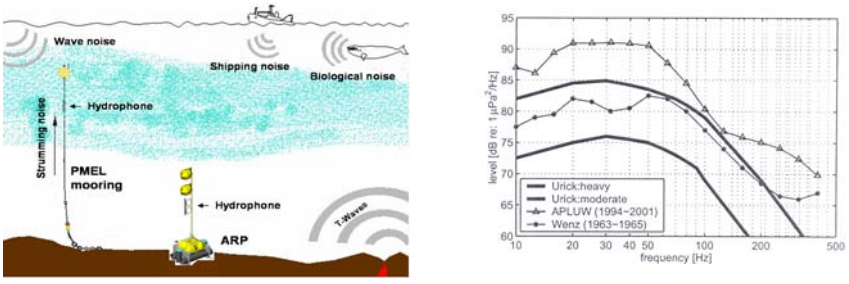
Introduction

Sound is integral in the lives of most marine vertebrates, as many species have converged on sound as a particularly effective mode of communication and orientation. Fish, marine mammals, sea turtles, and even some invertebrates have evolved functional and, in some cases, quite elaborate sound production and reception mechanisms (see Tavolga, 1964; Richardson *et al.*, 1995; Popper and Edds-Watson, 1997; Wartzok and Ketten, 1999; Popper *et al.*, 2004). For many marine animals, acoustic communication is

(photos courtesy: A. Friedlaender, P. Tyack, B. Southall, D. Nowacek)

central to social interactions such as mating and tending to offspring. Some species, such as dolphins and porpoises, actively use sound to feed and sense their environment (*e.g.*, Au, 1993). Others listen for predators and prey sounds, or to navigate in a vast, visually-opaque sea (*e.g.* Tyack, 1998, Schusterman *et al.*, 2000).

The ocean is far from a quiet place. Sounds from waves, animals, precipitation, earthquakes, wind, and other natural sources contribute to the background (or "ambient") acoustic environment, although humans have increasingly added sound into the sea throughout the Industrial Age. Many anthropogenic sound sources produce sound as a by-product of their operation (*e.g.*, commercial shipping). Others generate signals for the express purpose of locating objects or characterizing environmental features (*e.g.*, seismic surveys for oil exploration). Anthropogenic sound sources, either purposeful or incidental, can be intense, but those sources are typically rare or intermittent (*e.g.*, explosions, active sonars, pile-driving). Others may be relatively quieter but more continuous (*e.g.*, boats, dredging, drilling, and off-shore energy production and/or distribution terminals). Anthropogenic sound sources can affect marine ambient noise and, in some specific areas, appear to be resulting in increases over time of ambient noise at low frequencies (*e.g.*, Andrew *et al.*, 2002; McDonald *et al.*, 2006). However, such



Schematic diagram of various underwater sound sources and monitoring hydrophones (left; courtesy S. Moore) and low-frequency ambient noise measurements (right) at a site off California measured over a period of several decades (see Andrew *et al.*, 2002)

measurements have been relatively rare, and actual changes are expected to vary as a function of time, location, and other factors. The environmental implications of this human contribution to low frequency ambient ocean background noise are as yet poorly understood.

Over the past several decades, there has been increasing recognition, concern, and debate over the environmental effects of various anthropogenic sound sources. While certain sounds may be inaudible or entirely benign to marine animals, various adverse effects of noise have been documented, ranging from minor orienting responses to injury and even mortality (for detailed discussions see NRC 1994, 2000, 2003, 2005; Richardson *et al.*, 1995; Wartzok and Ketten, 1999; McCauley *et al.*, 2000; Popper *et al.*, 2004; Samuel *et al.*, 2005; Cox *et al.*, 2006; Nowacek *et al.*, 2007; Southall *et al.*, 2007).

While there has been much recent progress, including work supported by U.S. federal agencies, scientific knowledge remains limited. The biological significance of the varied effects of anthropogenic sound on marine life remains hard to objectively identify, or predict in realistic conditions, and as a consequence the potential overall magnitude of the issue remains unclear. In fact, a recent NRC (2005) report concluded that: "On the one hand, sound may represent only a second-order effect on the conservation of marine mammal populations; on the other hand, what we may have observed so far may be only the first warning signs or 'tip of the iceberg' with respect to sound and marine mammals."

Our inability to fully assess environmental impact is having significant implications for both federal agency activities, as well as private-sector interests. This

scientific uncertainty complicates management actions directed to minimize adverse impacts, including some impacts that are subject to speculation and hypothesis but that have not been scientifically documented. Additionally, the elements of the environment perceived most at risk are the marine mammals which are the subjects of protective legislation (*e.g.*, Marine Mammal Protection Act of 1972), and which enjoy a correspondingly high public interest.

These factors contribute to the frequent occurrence of acoustic-related litigation, longer review time for environmental risk assessments and other analyses and, in some cases, serious delays or other difficulties in obtaining regulatory approvals for activities important to our nation (*e.g.*, national defense, energy development, scientific research). Additionally, some of the mitigation and monitoring measures imposed during the regulatory process have costly, restrictive consequences. However, few of those measures have actually been tested to determine their actual effectiveness. The wide scope of potential impacts in very different conditions, coupled with limited available data on actual impacts, allows for widely divergent 'conclusions' on the relative magnitude of the issue relative to other human stressors (*e.g.*, climate change, overfishing, contaminants) and a broad diversity of opinion about the proper course of remediating action.

These disparate viewpoints were evident in a lengthy stakeholder panel recently convened by the U.S. Marine Mammal Commission under the Federal Advisory Committee Act (see MMC, 2006), which failed to produce the initially sought consensus regarding an appropriate course of scientific and management actions. Amidst this background of heightened awareness and differing opinions among conservationists,

scientists, managers, and sound-producing industries, the federal agencies must assess the best course of action in fulfilling their respective mandates.

The federal agencies are striving to improve requirements that address the matter of which sound-producing activities do or do not have actual impacts and how to mitigate anticipated adverse effects when a given activity is reasonably expected to pose a risk of impact. A particular challenge is achieving mitigation of noise impacts to protect the marine environment while not unnecessarily compromising important actions that produce sound (*e.g.*, mitigation of military sonar that might reduce national defense effectiveness). Agencies must comply with numerous environmental statutes before they are allowed to authorize or permit activities, including but not limited to: the National Environmental Policy Act (NEPA), Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), and Magnuson-Stevens Fishery Conservation and Management Act (MSA). These statutes all apply different requirements and thresholds for effects and individually impose mandatory mitigation and monitoring measures. Federal agencies are then faced with the difficult and at times conflicting tasks of fulfilling their public obligations in a data-poor environment and meeting statutory and regulatory requirements that are varied and, at times, conflicting. Ultimately, affected agencies benefit from coordinating their efforts to better define scientifically the environmental impacts of proposed major actions involving sound as well as the effectiveness and efficacy of mitigation and monitoring measures. Achieving this goal will move federal agencies away from addressing this issue according to their specific statutory mandates and instead entering into greater scientific collaborations that will better allow agencies to meet their mandates, define and reduce adverse impacts on the

marine environment and minimize adverse impacts to important U.S. government, scientific, and commercial activities.

Task Force Report: Scope and Structure

In response to these current and emerging challenges, there is an urgent need for a focused, coordinated science and technology plan of action among federal agencies. This report therefore represents a strategic vision for integrating and optimizing the research efforts of U.S. federal agencies over the next decade. This strategic vision is based on lessons learned from inter-agency coordination on ocean science issues generally, and emerging science on this issue specifically. Better scientific understanding of the issue leads to greater clarity, and therefore less basis for controversy.

The existing data on known and reasonably foreseeable adverse consequences of anthropogenic sound on marine life are limited (see: Southall *et al.*, 2007). Consequently, *the guiding principle of this strategic plan is to recommend actions that build the capacity to better document and respond to the actual environmental effects from anthropogenic sound.* Uncertainty about the scope of potential problems increases the risk that regulatory oversight of federal and private sector activities and the associated requirements for mitigating and monitoring sound emissions may be either insufficient or excessive, or even unnecessary, in some cases. Since many of the necessary technical capabilities and scientific understanding needed to better diagnose the problem are also integral to mitigating it when it is understood, we should not treat understanding and mitigation as two purely dichotomous activities. Many efforts required to improve understanding, such as improving marine animal detection and monitoring capabilities,

will also be needed for more effective mitigation action if and when a problem is identified. However, improving our understanding of the problem itself is the best and most immediately effective action that agencies can take toward resolving uncertainty and determining the most effective immediate course of action.

This report identifies and prioritizes research in specific areas that is required to better understand and address the demonstrated, hypothesized, and as-yet unconsidered adverse effects of anthropogenic sound on the marine environment. Implementing this coordinated scientific strategy, should provide sound-producers and decision-makers with the data and technical capabilities needed to ensure a safe and healthy marine environment while avoiding unnecessary constraints on U.S. federal agencies and private enterprise.

Chapter 2. Current U.S. Federal Research and Development Effort

Chapter 2 – Key Points
• **Some federal agencies already support or conduct research and development in this field.** • **USN, MMS, and NSF have traditionally been most active in supporting science and technology on this issue, with NOAA, MMC, FWS, and several other agencies playing lesser overall roles.** • **Specific research efforts are divided into five general subject areas (see *Appendix II*).** • **Despite this effort, available information is still insufficient to support non-controversial assessments of environmental risk or to effectively mitigate the potential adverse effects of anthropogenic sound.**

Regulatory requirements and increasing public awareness of and interest in possible environmental impacts from anthropogenic underwater sound have generally driven federal research and development. Efforts to date have been strongly affected by the specific requirements of a few agencies and the targeting of certain actions (*e.g.*, the use of military sonar and seismic airguns) by environmental groups. This focus has often limited the extent to which data or capability developments have been effectively applied to a broader set of relevant conditions, user needs, or basic scientific questions. For instance, active sound sources (such as seismic airguns and down-looking research sonars) are vital to the geophysical and oceanographic research objectives of numerous academic research groups, as well as all federal agencies operating or supporting marine activities using oceanographic research vessels. The results of such studies are proving to be essential in safety of marine navigation, understanding historical climate patterns needed to interpret climate change, geological variables relevant to understanding the risk of tsunami, possible extension of the U.S. continental shelf to include resource-rich areas,

and other timely and important issues. Given the significance of active sound sources in basic marine research, NSF has directed some research effort toward understanding characteristics and potential environmental impacts of some of these sources, seismic airguns in particular. Similarly, MMS has focused on understanding the effects of specific sources involved in locating and extracting offshore hydrocarbon deposits and removing offshore oil and gas platforms (which include seismic airguns as well as explosions).

The impacts of active sonar systems used in military applications are another area of particular interest. A wide array of military sound sources used in training and readiness (*e.g.*, sonars and explosions) are of critical importance to the mission of the U.S. Navy to ensure national security. Navy-funded research and public interest in the potential environmental effects of military sources has intensified following a series of high-profile marine mammal stranding events associated with specific kinds of tactical mid-frequency military sonars (see Cox *et al.*, 2006).

In contrast to these highly-focused, mission-relevant areas of emphasis, other agencies have mandates for understanding, managing, and mitigating the adverse effects of a wider range of human sounds on marine mammals (MMC) and marine life (NOAA, FWS). These agencies are broadening their focus and expertise, based on the increasing realization that sound sources such as large vessels, pile driving, offshore energy development, navigational and/or imaging sonars, and oceanographic research sources may be of concern in addition to the naval and geophysical sound sources currently receiving the greatest attention. While some of these sources may lack the instantaneous output power of some of the powerful active sonars and seismic airgun sources, many of

them occur in far greater numbers and cover much greater geographical ranges and deployment times than more intense, acute sounds. The potential for impact from certain lower-power but more ubiquitous sources is increasingly being considered and scientific measurements are required to inform these considerations. Some of this broadening of focus and expertise is occurring within the federal agencies. However, competing priorities have hindered the regulatory and oversight agencies (NOAA, FWS, and MMC) from directing resources they would need to support or conduct research consistent with their statutory obligations for regulation and oversight.

Public perception of threats and scientific analyses of risks may lead to different priorities for acoustic research. There is increasing concern by scientific experts in relevant disciplines that the public and legal focus on a very narrow range of active sources and the predictable agency responses are distorting an appropriate scientific approach to assessing the broader impacts of anthropogenic noise as a global issue (see NRC, 2000; 2003; 2005; Nowacek *et al.*, 2007; Southall *et al.*, 2007). This creates a growing need for both transparency and public and stakeholder outreach as agencies respond to the increasing awareness of sound as an environmental issue.

Historically, USN, MMS, and NSF have been the most active in investigating marine sound impacts and use of sound in the oceans. Resulting research has been focused primarily but not exclusively on marine mammals and a subset of anthropogenic sound sources. Other federal agencies (notably NOAA, MMC, and FWS) are playing a limited but slowly growing role in also conducting or supporting non-government entities in science and technology development. Specific research activities conducted or supported by these agencies is described below and in much greater detail in Appendix II.

A condensed summary of current federal effort is given here in each of the following five general subject areas identified by the Task Force: *(1) Sound Sources and Acoustic Environment; (2) Baseline Biological Information (Physiology, Distribution, and Abundance); (3) Effects of Sound (Criteria and Thresholds); (4) Monitoring and Mitigation; and (5) Outreach, Education, and Scientific Peer Review.* [Note: see *Appendix II* for a more detailed description of specific science and technology efforts by the individual federal agencies in each area.]

(1) Sound Sources and Acoustic Environment

Research in this area has included measurements and modeling of various anthropogenic and natural sound sources, how the sounds they produce then travel (or propagate), and the interaction of anthropogenic sound with natural sound to affect overall marine ambient noise. USN has supported extensive work on propagation models, measurements of military and biological sound sources, and signal processing technologies, both for environmental compliance and military tactical applications. This work has resulted in many of the existing state-of-the-art technologies for predicting radiated sound fields from specific sources used in the context of assessing potential impacts, among other accomplishments. Subsequent effort in certain aspects of this general area (*e.g.*, propagation modeling) is thus a much lower priority than other key topics for which less effort has been expended.

Similarly, NSF and MMS have investigated the acoustic properties of active sound sources used for seismic surveys – activities of particular interest to those agencies. These have included field measurements and source characterization of seismic airguns and other technologies used in geophysical research and industrial sources used in

visualizing mineral deposits. While there are important differences among these sources that require multiple lines of investigation, this is perhaps an example of where collaboration of effort across agencies to meet common research needs might have improved the overall efficiency and power of the results. Nevertheless, these substantial measurements similarly decrease the urgency of obtaining similar such measurements, at least relative to the other pressing needs facing federal agencies.

NOAA and MMS have increasingly begun applying passive acoustic technologies in surveys of the marine animals. For instance, NOAA has, in conjunction with academic researchers and others, deployed acoustic listening sensors to determine the seasonal presence and activity of endangered right whales in Stellwagen Bank National Marine Sanctuary, various large whales in Arctic areas, and the responses of marine mammals to shipping activity near the busy port of Long Beach. Some of these (and other) deployments are research to better understand basic biology and ecology of protected species, whereas others have a more applied conservation management purpose (such as the use of listening sensors to localize right whales and report that information to vessels in an effort to minimize ship strikes). Finally, NOAA has begun to take a somewhat unique, broader interest than other federal agencies in how collective human activities may affect animals through increases in overall marine ambient noise. While research in this area has been limited, NOAA has begun working with USN to recover and analyze historical measurements of ambient noise from decades ago. NOAA is also supporting subsequent measurements of marine ambient noise, in

"Pop-up" passive acoustic recorders (courtesy: C. Clark)

order to expand the scientific understanding of potentially increasing low frequency noise.

(2) Baseline Biological Information (Physiology, Distribution, and Abundance)

There have been substantial efforts to generate baseline biological information, but the complexities in natural systems render this an inherently challenging research area. In many cases, a limiting factor in assessing potential impacts has been uncertainty regarding species presence and abundance in the area of concern, requiring additional costly survey effort to produce the needed information. Surveys of animal distribution, as well as baseline measures of anatomy and physiology, have been conducted by management agencies (NOAA and USFWS) in some areas. Other agencies (USN, MMS, and MMC) have supported similar efforts in specific geographical locations of interest to those particular agencies. These surveys form the basis of current knowledge used, among other places, in environmental assessment and compliance documentation. Certain species (*e.g.*, bottlenose dolphins, grey whales, California sea lions) appear to be fairly well understood in terms of their general distribution, population trends, and basic anatomy as a result of these efforts. However, many key species (*e.g.*, beaked and other deep-diving whales, Arctic ice-breeding seals, most marine fish) remain quite poorly understood in many key aspects of natural history.

Various animal tagging technologies (developed largely through support from USN are becoming critical in supporting and validating distribution models, as well as conducting research on the behavioral responses of marine

Acoustic tag attached to a northern fur seal (courtesy: S. Insley)

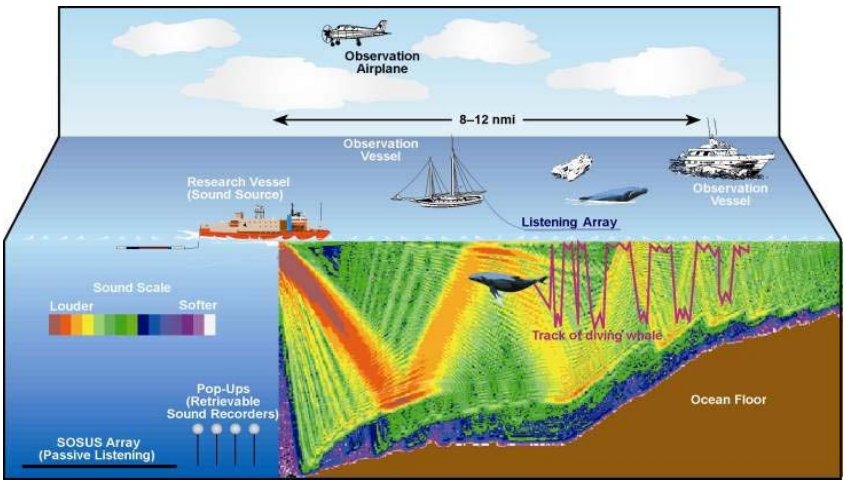
animals to anthropogenic sound. A large body of information has also been generated through mandatory environmental compliance monitoring by both federal agencies and private sector activities, but these valuable data have not been systematically archived, analyzed, or made readily available for use in subsequent risk assessment and mitigation actions, often due to limited resources and/or technologies for systematically archiving the data in a manner useful for subsequent analyses. This represents an important area for progress with relatively lower additional effort than in other areas, with potentially large impact to not just the marine noise issue but in terms of value added to other environmental compliance and conservation management efforts.

(3) Effects of Sound (Criteria and Thresholds)

U.S. federal agencies have also supported and/or conducted direct measurements of the effects of sounds on marine life to support science-based acoustic exposure criteria, with substantive advances in specific areas. Research on the effects of noise on hearing has proven more definitive and broadly-applicable than quantifying the biological significance of behavioral responses to sound (see NRC, 2003; 2005; Southall *et al.*, 2007). Uncertainty regarding which exposures are consistent with demonstrated adverse impacts (particularly behavioral responses) and the overall potential magnitude of environmental impacts from noise are perhaps the greatest obstacles to determining the appropriate federal response. For this reason, we have prioritized this particular area of investigation highly in the recommendations made throughout this strategic plan.

USN (and to a lesser extent NOAA) has funded research on how noise can affect the hearing, behavior, and physiology of certain marine mammal species. These measurements form the current basis for marine mammal noise exposure criteria

(Southall *et al.*, 2007). However, they are limited in many ways, including the fact that a very small percentage of the total number of species have been tested, almost always with small sample sizes, and most of the work has been conducted in laboratories on captive animals that may not fully represent free-ranging individuals for certain types of effects (*e.g.*, natural behavioral patterns). A significant current collaboration of USN and NOAA is facing the daunting task of understanding the nature and scope of behavioral responses to specific anthropogenic sounds (including active military sonars) using controlled exposure experiments to obtain empirical measures of behavior in the wild.



Simple schematic of nominal behavioral response study elements (source: R. Gisiner).

MMS has also provided considerable support for distribution patterns of marine mammals during and after oil/gas exploration and production, including key studies on noise impacts. These included observational and controlled studies on marine mammals over the last two decades monitoring responses to seismic surveys and other aspects of oil and gas exploration and production. The resulting data are significant and represent much of the current understanding of whether and how certain large whale species

typically respond to such sounds. However, certain key questions remain about such impacts even in those species studies, and many key species (especially in Arctic areas) have not been systematically tested. FWS has similarly assessed manatee behavior relative to boat operations. Finally, NSF provided use of its former seismic research vessel (*R/V Maurice Ewing*) for use in controlled exposure experiments in research lead by MMS, with support from ONR, NMFS, and private industry (see Jochens *et al.*, 2008).

(4) Monitoring and Mitigation

Once specific impacts are demonstrated or reasonably likely to occur under specific conditions, choosing effective monitoring and mitigation measures is important for minimizing both environmental risk from anthropogenic sound and the impact of these requirements on human activities that generate sound. At present, a number of monitoring and mitigation measures are required of federal and federally-funded researchers, and private enterprise to mitigate environmental risk from sound-producing activities. However, most, if not all, are undocumented in their efficacy and carry financial or logistic costs that impose serious (and possibly unnecessary) burdens on agency mission effectiveness.

USN has supported considerable technology development to enhance detection methods for marine life using a variety of modalities. For instance, the use of passive acoustic monitoring (PAM) on military ranges to locate and track some marine mammals is proving to be an increasingly useful tool in determining reactions to sounds involved in military operations. Additionally, active acoustics, radar, infrared imaging, and other methods are expanding the methodological toolkit available for use in sensing and characterizing marine mammals around operations. MMS, NSF, NOAA, and FWS have

supported related efforts, mainly in the realm of using PAM for marine mammal monitoring. Specific examples include the use of listening sensors to localize endangered right whales in Stellwagen Bank National Marine Sanctuary (NOAA) and NSF work using PAM aboard the *R/V Marcus G. Langseth* for marine mammal monitoring.

(5) Outreach, Education, and Scientific Peer Review

All of the involved federal agencies concur on the need for public awareness and understanding of this complex and evolving issue. This is particularly in the face of often-inaccurate or sensationalized depictions in the media and various public fora. For example, a recent cover of the Honolulu Weekly (Vol. 18, no. 12; March 19-25, 2008) depicts active sonar as an "all purpose killer" and "anti-marine life military power" that "kills whales on contact". Such emotionalized hyperbole confuses the public and some decision-makers into believing conclusions that are wildly inconsistent with reality, amplifying the divisiveness and acrimony that has unfortunately become synonymous with this issue.

Most of the federal agencies participating in this task force have contributed to public outreach and scientific peer-review to some extent, the most notable examples being the series of National Research Council reports (1994; 2000; 2003; 2005) and the peer-reviewed, award-winning Discovery of Sound in the Sea (DOSITS) educational website (www.dosits.org) operated through the University of Rhode Island.

Dr. William Ellison delivering an educational lecture at the National Aquarium in Washington D.C. as a part of NOAA's educational lecture series on marine acoustics (photo credit: NOAA)

Chapter 3. Science and Technology Directions for U.S. Federal Agencies

Chapter 3 – Key Points
• **Targeted research in key areas, coordinated across agencies, is in the vital interest of the U.S. government, the public, and the biological resources we seek to protect.** • **Specific, prioritized science and technology objectives are discussed (briefly here and in greater detail in *Appendix III*).**

A full understanding of the complex suite of relevant questions for tens of thousands of marine species is simply impossible, regardless of the amount of effort by federal (or other) sources. However, through targeted, proactive, and integrated research and development, federal agencies can provide greater confidence in decisions about mandated conservation requirements. In an effort to develop a strategic roadmap toward this objective, the Task Force determined research priorities in a sequential manner:

- First, the Task Force gathered information regarding the roles and responsibilities of the involved agencies (see Appendix I) and agency efforts to date in addressing this issue from a scientific perspective (see Appendix II).
- Next, the Task Force underwent a series of discussions centered on reviewing Appendices I and II and individual agency scientific priorities on this issue and identifying specific research action areas. These actions items were considered within the five general subject categories (Sound Sources and Acoustic Environment; Baseline Biological Information; Effects of Sound; Monitoring and Mitigation; and Outreach, Education and Scientific Peer Review).

- The Task Force then prioritized research action areas within each category according to three levels of importance (*highest*, *high*, and *moderate*; below and see Appendix III).
- Finally, the resulting highest priority subject areas for federal research were coalesced into a recommended strategic plan of prioritized research recommendations that includes an ordinal ranking of priorities as well as a simplifying approach that considers not only the relative importance of the work, but also the respective level of effort required (see Chapter 5; Table 1).

Summary of Prioritized Research Needs by Subject

(1) Sound Sources and Acoustic Environment

- Highest priority:
  - Passive and/or active acoustic deployments to detect and characterize biological and anthropogenic sound sources and ambient noise (including trends) [needed to enhance animal detection for improved mitigation measures, and improve overall understanding of specific sources and the full scope of anthropogenic contribution to marine noise]; and
  - Characterize/verify measurements for specific sources of highest immediate concern (*e.g.*, ice-breaking, certain military sonars, seismic airguns, new classes of large vessels) [needed to accurately predict noise fields around specific real-world sources in order to estimate potential impacts].
- High priority:
  - Sound source verification for new wide-azimuth seismic surveys, pile driving, as well as oil drilling and production [need is same as above, just slightly lower priority].
- Moderate priority:

- Characterize/verify measurements of additional sources (emerging or less prevalent technologies than in the above category – *e.g.*, offshore alternative energy technologies, underwater data communications, oceanographic research or mapping sonars, acoustic harassment and deterrent devices) [need is same as above, just slightly lower priority]; and
- Develop online data archives of sound source data [needed to provide existing data on sources of interest for use in impact assessment and to reduce probability of duplication of effort].

(2) Baseline Biological Information (Physiology, Distribution, and Abundance).

Determining baseline biological and life history data for marine life generally is beyond the scope of this report, as it is not strictly specific to acoustic issues. There is ongoing work in those areas, as well as additional efforts needed, much of which is relevant to a complete assessment of the impacts, both direct and cumulative, of specific sounds on marine life. What is intended in this section is basic biological information relating specifically to the marine noise issue (perhaps considered baseline acoustical information) as well as direct information on the effects of noise on hearing, behavior and physiology.

- <u>Highest priority</u>:
  - Develop, standardize, integrate, and maintain online databases of marine mammal distribution, abundance, and movement (it is worth noting the considerable value-added aspect of this action relative to other marine resource management issues such as fisheries, monitoring of marine protected areas) [needed to provide a common source of data access and management of information used in both managing and studying these species];
  - Improve distribution and abundance measurements for key species (*i.e.*, very common, endangered, or particularly important to specific types of sound sources) [needed to increase the biological precision of impact assessment and targeted mitigation efforts]; and

- Obtain baseline biological data on "particularly sensitive" (*e.g.*, beaked whales, harbor porpoise, migrating bowhead whales) and Arctic marine species (because of the apparently rapid climatic and habitat changes they are experiencing and the increasing human activities in Arctic areas) [needed to better understand and manage species of particular concern for various reasons]

- <u>High priority</u>:
  - Obtain targeted physiological, behavioral, distribution, and longitudinal life history data for "representative" marine species (those thought to adequately represent related species on which such data are not available – see NRC, 1994, 2000, 2003) as surrogates for less-common or more-difficult-to-test species [needed to provide a more complete understanding of a few relatively accessible species that may be appropriate surrogates for estimating some impacts in other species].
- <u>Moderate priority</u>:
  - Develop specific assays for stress and immune functions [needed methodology to assess the potential impacts of noise exposure on certain non-auditory tissues and processes].

(3) Effects of Sound (Criteria and Thresholds)

- <u>Highest priority</u>: develop, improve, and/or validate noise exposure criteria by:
  - Obtaining advanced measurements of hearing (*e.g.*, evoked potential audiometry and sophisticated behavioral methods) [needed to more rapidly obtain basic hearing data, including on certain species that may be unavailable for more conventional hearing methods];
  - Testing hypotheses on the non-auditory, physiological effects of noise [needed assessments to assess recent observations of specific types of non-auditory tissue damage in animals exposed to certain sound source as well as expected phenomena based on non-marine animals];
  - Obtaining measurements of the behavioral effects of high priority sound sources in key sensitive (*e.g.*, beaked whales) and representative (*e.g.*,

common dolphins, minke whales, salmon) species [needed to provide direct measurements of how key species respond when hearing specific sounds; for use in impact assessment, monitoring and mitigation efforts, and/or development of alternative source technologies (where appropriate and possible)]; and

- Quantify the actual biological consequences of signal masking [needed to understand the real biological costs of simultaneous noise interference with communication in marine animals].

- High priority:
  - Measure acoustic perception/localization for realistic signals over realistic noise exposures [needed to advance the state of current hearing data to include some measurement of how actual biological and other sounds are actually perceived and located in space – current data are generally limited to artificial stimuli]; and
  - Advance anatomical modeling capabilities to predict various effects, especially where *in vivo* testing is difficult [needed to provide science-based estimates of potential impacts in situations where direct measurements may not be possible].
- Moderate priority:
  - Measure (following development of specific assays – see above) effects of noise on stress and immune functions, including synergistic effects [needed measurements to assess potential impact of noise exposure on non-auditory tissues that may be expected to occur in certain circumstances based on non-marine animals].

(4) Monitoring and Mitigation

- Highest priority:
  - Improve/advance remote sensing technologies for marine mammals [needed to enhance detection of marine mammals in the contexts of both scientific research and mitigation of potential impacts from certain sound sources];

- Validate new and existing mitigation measures [needed to provide scientific assessment of and possible improvements to procedures currently in place];
- Investigate source modifications to reduce acoustic footprints [needed to consider whether reductions of the acoustic output of certain sources may be possible based on function(s) and other practical considerations; and
- Explore need for and effectiveness of time/area closures versus operational mitigation measures [needed to consider which approach, or some combination thereof, may be more appropriate and best suited to a particular operational scenario].

- High priority:
  - Improve/advance remote sensing technologies for other marine species (*e.g.*, sea turtles, fish, squid) [needed to enhance detection of species other than marine mammals in the contexts of both scientific research and mitigation of potential impacts from certain sound sources]; and
  - Standardize observer program data collection and reporting [needed to ensure that observed data being obtained is accessible to others conducting impact assessments in a useful and common format].
- Moderate priority:
  - Develop and validate simple decision-making criteria for source shutdown, modification or movement [needed to provide a common set of protocols for modifying sound-producing activities, where appropriate].

(5) Outreach, Education, and Scientific Peer Review

- Highest priority:
  - Develop a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government, industry, academia, public, educators, media, and environmental groups) [needed to provide a regular and transparent exchange of information regarding progress and research directions within and among federal agencies and various stakeholders];

- Encourage timely peer-reviewed publication of scientific data supported with federal funding [needed to ensure that federally-funded research is made available in a scientifically-acceptable format]; and
- Conduct periodic expert panel reviews of existing scientific data in the relevant fields [needed to assess current status of science and how it may be applied, as well as to assess additional needed research].

- High priority:
  - Enhance the availability of educational/outreach material, including effort directed to K-12 education, oceanaria, marine reserves, and interest groups [needed to ensure that scientific information on this issue is fairly and transparently communicated to society through a variety of acceptable and known conduits].

Chapter 4. Inter-Agency Coordination Mechanisms: Opportunities and Obstacles

Chapter 4 – Key Points
• **There are existing coordination mechanisms within and between federal agencies on the issue of anthropogenic sound impacts.** • **Sustained and expanded dialogue among agencies is extremely important on both domestic and international issues related to anthropogenic sound.** • **Ample opportunities exist to further the diverse capabilities and perspectives represented in the combined federal agencies.** • **Significant challenges to progress also exist. These include differing and often complex budgeting and permitting processes, as well as increasing litigation of both ongoing activities and research designed to inform conservation management**

Key elements in implementing any coordinated federal strategic plan are (1) identifying existing and needed coordination mechanisms among the federal agencies and (2) an objective assessment of opportunities and challenges in successfully enacting the envisioned course of action(s). For a highly visible, contentious, and data-poor issue such as the effect of anthropogenic sound on marine life, these elements take on even greater significance. This chapter briefly addresses these key considerations.

Existing Coordination Mechanisms

Many of the federal agencies that have been dealing extensively with this issue either as sound-producers or in a regulatory function have developed internal coordination and communication mechanisms. These are *ad hoc* in some cases and more structured in others, but are generally intended to enhance communication and consistency across different branches within those agencies.

In terms of inter-agency communication, there are also existing mechanisms, ranging from informal (such as the Inter-agency Coordinating Group (ICG) on ocean sound) to much more structured mechanisms for coordination of funding efforts (principally the National Oceanographic Partnership Program (NOPP)).

While communication and coordination can and will continue to improve among federal agencies, there is also a need for increasing international discussion and collaboration. There is a growing international scope of this issue, a trend that will likely continue, involving many of the federal agencies and coordination by DOS. In addition, many industries (*e.g.*, commercial shipping, energy exploration and development) and federal agencies (*e.g.*, NSF, USN) affected by the regulation of sound-producing activities also operate internationally and, in many cases, face differing regulatory mechanisms and mitigation and monitoring requirements depending on the location. This further reinforces the need to also look globally for information sharing and solutions to this issue. For instance, the United States recently proposed to the International Maritime Organization's Marine Environmental Protection Committee (MEPC) that it add to its work agenda the issue of minimizing the introduction of incidental noise from commercial shipping to reduce the potential adverse impacts on marine life. In October 2008, the Committee agreed with the U.S. proposal. This work is a prime example of interagency cooperation addressing sound issues in the international arena. In addressing this issue, the correspondence group established to work on it will begin to assess and identify practical, effective solutions to this issue, and work on the development of non-mandatory technical guidelines for ship quieting technologies as well as potential navigation and operational practices.

Opportunities for Inter-agency Coordination

Currently the science and technology efforts of the federal agencies are primarily driven by individual agency needs. There are collaborative approaches to certain questions, for example through NOPP or interagency research agreements, but agency science programs generally identify and support research meaningful to specific agency mandates. This is logical and not necessarily something that requires change.

However, there is an opportunity within the inter-agency collaborations that have been initiated to maximize the diverse capabilities and perspectives of the federal agencies in moving the overall issue forward. Many of the research needs of federal agencies have some overlap or commonality. For instance, tools and technologies to improve the detection and characterization of marine life will benefit all participating agencies. Better understanding of animal distribution, abundance, and life history, particularly as it relates to acoustic communication and potential noise impacts, will improve the abilities of agencies that utilize sound-producing technologies to determine and mitigate their potential environmental impacts, as well as enhancing the abilities of regulatory agencies to fulfill their obligations. Further, some uniformity of effort, peer-review, and information transfer to the public and educational programs (*e.g.*, availability of on-line databases and other resources) are common goals of all involved federal agencies. Certain categories fall more logically within the mandates and expertise of certain agencies rather than others, and this issue is addressed in greater detail in Chapter 5. However, there is a pressing need at the federal level for a more unified and integrated strategic approach on a topic that is becoming increasingly broader and more complex.

The strategic federal response on marine sound must be coordinated, yet optimized to the individual strengths of the individual agencies and adaptive in responding to this rapidly-evolving field. Therefore, while the Task Force is keenly aware of the potential downside in adding additional layers of bureaucracy, we do see a clear need in formalizing coordination among the agencies at two different levels. This should include:

- Program-level coordination of managers and scientists intimately familiar with the status and future directions of science in relevant subject areas (as well as how they relate to federal agency missions) to formulate action plans for achieving specific goals and milestones, and facilitate program level interagency interaction on specific projects, data sharing, etc.; and
- Higher-level agency representatives with sufficient authority to make internal budgeting and planning recommendations and decisions that relate to future needs and obligations for partnerships with other federal agencies.

The overall aim of each of these inter-agency mechanisms should be to coordinate mutual research goals, projects, data management/sharing, and co-funding opportunities in the short term, but, more importantly, to also coordinate advanced planning across the federal agencies with sufficient lead time to constructively affect the federal budgeting process.

Potential Obstacles for a Federal Research Strategic Plan

Long-term collaboration will require coordinated efforts for informing budget planning processes within all relevant agencies. Currently, internal agency processes for

setting goals occur in the absence of knowledge of whether another agency will be able to collaborate in future years on mutual needs. While it is difficult enough to plan within individual agencies several years out, much less on an issue across multiple agencies, there should be some coordinated thought and sustained discussion given to both short and long-term fiscal requirements for the involved agencies in a manner that is consistent with overall federal need. This will allow the Executive Branch to make a stronger case to Congress that it is properly addressing an issue of high public and Congressional interest, which spans the actions of multiple agencies.

Additionally, there are considerable challenges in terms of planning and conducting many of the kinds of research proposed here. Some of these challenges have to do with the regulatory/permitting procedures required under various federal laws, which can be difficult given the level of required analysis, current levels of scientific uncertainty, and the contentious political-legal climate of the overall issue. These processes can be time-consuming, expensive, and variable across jurisdictions (which can include federal, state, local, and institutional authorizations), sometimes resulting in the postponement or canceling of critical activities (*e.g.*, operation of mid-frequency military sonar off the west coast, oil exploration activities in Arctic Alaska waters), or re-prioritization of limited available research support. Further, complex and often protracted permitting processes are also making it increasingly difficult to synchronize the application for and acquisition of research funding. Resources and effort should be focused on streamlining and improving the necessary permitting and regulatory processes at the federal level, particularly for those research efforts that will feed data on acoustic effects back into the regulatory process.

Finally, there are certain societal realities that may impede scientific progress on the marine sound issue, notably lawsuits. In some instances, litigation has served as an effective mechanism for balancing the federal regulatory and decision-making process where needed. In other examples, lawsuits appear to be mainly driven to draw an agency into lengthy legal disputes with federal agencies spending valuable resources to defend actions the court ultimately upholds. The increasingly litigious response has affected the USN, NOAA, NSF, MMS, academic researchers, and others. The effective use of scientific information to formulate regulations and enhance decision-making rather than controversy and litigation formulating what science can be effectively accomplished is a complex process, perhaps requiring some adjustments for this issue. Procedures exist to help ensure reasonable and effective decision-making and regulatory responses. No explicit suggestions are provided in this report to reduce the negative consequences of increased litigation, but it is identified as a significant factor that may cause delays, increase costs, or otherwise limit various types of research and development and ultimately not lead to a better understanding of sound impacts on the marine environment. Further, we note that the improved understanding and ability to take effective action which will arise from the actions recommended in this report are likely the best means to resolve strong divergences of opinion that lead to litigation, as well as to provide federal agencies the ability to defend themselves in future court cases that do arise.

Chapter 5. Conclusions and Recommendations

Chapter 5 – Key Points
• **The general coordination and specific research recommendations made in this report represent a strategic vision to develop targeted, coordinated, inter-agency science and technology efforts, over the short and long-term on the effects of sound on marine life.** • **General recommendations include: actions directed to increase and sustain coordination within and among agencies and with private-sector and international organizations; continued efforts to streamline the scientific research process; and developing a biennial forum for information transfer on the results of inter-agency research efforts and planning.** • **Eleven (11) specific research recommendations are given in prioritized order and within subjective categories relating their relative importance and required level of effort.** • **Additional high and moderate research priorities (see Chapter 3 and *Appendix III*) provide additional guidance.**

The information to follow outlines the Task Force's strategic vision for integrating, prioritizing and optimizing the science and technology efforts of federal agencies on marine anthropogenic sound over the next decade. From these deliberations, the Task Force has derived an overall prioritization of needed research action areas, with specific examples of research topics within these action areas. Further, the plan presented here also provides some information on the timeframe for these actions (short-term, long-term, or ongoing), relative effort required for implementation, and the federal agencies most likely to be involved in a specific action area. Collectively, this information presents the Task Force's strategic plan for addressing the pressing requirements of a coordinated federal response.

The recommendations of the Task Force are given in two areas: necessary actions to ensure a coordinated federal response and specific research action area priorities for

the coming decade (below). Again, it should be realized that this report represents an overall, interagency perspective as determined through the Task Force members and the views given here do not necessarily reflect individual agency priorities. Highest priority coordination action items include:

Sustained interagency collaboration and coordination, including:

- "High-level" inter-agency coordination among individuals with sufficient authority to make timely planning and budget recommendations within their respective agencies; and
- "Program level" inter-agency coordination among agency subject matter experts and program managers to implement directives and provide technical advice to leadership.

- **Enhanced communication and coordination on the marine sound issue with private sector interests and with the governments of other nations to reduce duplication of effort and advance a consistent scientific response.**
- **Continued efforts to streamline research permitting involving acoustic sources.**
- **Development of a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government agencies, industry, academia, public, educators, media, and environmental groups).**

In addition to these recommended coordination items, Table 1 (below) identifies the top eleven specific research action areas presented in an ordinal ranking of overall importance. Suggested timelines (*i.e.*, short-term vs. long-term) for these action areas

within the five general subject categories and those agencies most likely to have leading/direct interest and/or secondary level of involvement are also given. Additionally, each recommended research action area is assigned to one of four subjective categories according to the relative level of effort required to make significant progress and the overall importance and social relevance of the work: (1) High importance/moderate effort; (2) High importance/high effort; (3) Moderate importance/moderate effort; (4) Moderate importance/high effort.

Table 1 – Ocean Sound and Marine Life: Prioritized Research Recommendations

Prioritized Recommended Federal Research Action Areas	Short or Long-term?	Relative Importance and Level of Effort	Agencies Involved (see note below)	General Subject Area(s) (described in Chapter 2)
(1) Improve ability to identify and understand biologically-significant effects of sound exposure in order to improve effectiveness and efficiency of efforts to mitigate risk.	On-going and long-term	**High Importance/ High Effort**	NOAA[1]MMC[2] NSF, USN, MMS	Effects of Sound
(2) Hearing, physiological, behavioral, and effects data (*e.g.*, controlled exposure studies) for key species of concern (baleen whales, beaked whales, Arctic & endangered species).	Ongoing and long-term	**High Importance/ High Effort**	USN[1], NOAA[2], NSF, MMS, MMC	Baseline Biological Information; Effects of Sound
(3) Develop new technologies (*e.g.*, acoustic monitoring) to detect, identify, locate, and track marine mammals, in order to increase the effectiveness of detection and mitigation.	Ongoing and short-term	**High Importance/ Moderate Effort**	USN[1], NOAA[1], MMS, NSF, USCG, ACE, DOT, FWS	Sound Sources and Acoustic Environment; Mitigation and Monitoring
(4) Develop and validate mitigation measures to minimize demonstrated adverse effects from anthropogenic noise.	Short-term and long-term	**High Importance/ High Effort**	NOAA[1], MMC[2], USN, MMS, NSF, FWS, USCG, ACE	Mitigation & Monitoring; Effects of Sound
(5) Support the development, standardization, and integration of online data archives of marine mammal distribution, abundance, and movement for use in assessing potential risk to marine mammals from sound-producing activities.	Ongoing, short, and long-term	**High Importance/ Moderate Effort**	NOAA[1], USN, FWS, MMS, MMC	Baseline Biological Information
(6) Long term biological and ambient noise measurements in high-priority areas (*e.g.*, Arctic, protected areas, commerce hubs).	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1] USN, MMS	Sound Sources and Acoustic Environment
(7) Test/validate mitigating technologies to minimize sound output and/or explore alternatives to sound sources with adverse effects (*e.g.*, alternative sonar waveforms).	Long-term	**High Importance/ High Effort**	USN[1], NSF[1], MMS[1], NOAA, MMC, DOE	Mitigation & Monitoring
(8) Explore need for and effectiveness of time/area closures versus operational mitigation measures.	On going and long-term	**Moderate Importance/ Moderate Effort**	MMS[1], NOAA[2], MMC[2], USN, NSF	Mitigation and Monitoring
(9) Develop and improve noise exposure criteria and policy guidelines based on periodic reviews of best available science to better predict and regulate potential impacts.	On going and long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMC[2], USN, MMS, NSF	Effects of Sound
(10) Standardize data-collection, reporting, and archive requirements of marine mammal observer programs.	Long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMS, NSF, USN, USCG, MMC	Mitigation and Monitoring
(11) Expand/improve distribution, abundance and habitat data for marine species particularly susceptible to anthropogenic sound.	Ongoing and long-term	**Moderate Importance/ High Effort**	NOAA[1], FWS[1], USN, MMC, MMS	Baseline Biological Information

Note:
[1] denotes agencies that are the logical "action" leads on each recommended action
[2] denotes agencies that are the logical "oversight/coordination" leads on each recommended action

Conclusion

This strategic plan is intended to both substantially increase scientific understanding of the most pressing issues and reduce the costs, limitations to agency mission capability, and litigative burden on the government which currently attends this unsettled matter. Scientific uncertainty drives, if not allows, much of the current debate and disagreement on this issue. The application of targeted science through a coordinated, multiple agency effort directed towards identifying the nature and scope of real and potential problems, will provide answers to reduce uncertainties and ultimately result in more effective federal decision-making on important marine conservation issues.

This is a tractable matter. There are many opportunities for collateral benefit in areas of basic biology, biomedical science, oceanography, marine geology, climate science, and marine resource management and conservation. Many federal agencies have achieved considerable progress already on this and other issues through the use of available informal and formal mechanisms for cost-sharing, information transfer, and division of labor according to individual agency capabilities and mandates. Effective resolution of the myriad challenges in the marine noise issue must enable the agencies to more fully carry out their missions while meeting environmental requirements. This will enable the government to better serve the public and private sectors through more informed, effective action for the protection of our shared ocean environment.

Literature Cited

Andrew, R. K., B. M. Howe, and J. A. Mercer. (**2002**). Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online **3**, 65-70.

Au, W. W. L. (**1993**). *The sonar of dolphins* (New York: Springer-Verlag).

Cox, T. M., T. J. Ragen, A. J. Read, E. Vos, R. W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, P. D. Jepson, D. Ketten, C. D. MacLeod, P. Miller, S. Moore, R. D. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Mead, and L. Benner. (**2006**). Understanding the impacts of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7, 177-187.

Jochens, A. D., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. (2008). Sperm whale seismic study in the Gulf of Mexico: Synthesis report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-006. 341 pp.

McCauley, R. D., Fewtrell, J., Duncan, A. J., Jenner, C., Jenner, M. N., Penrose, J. D., Prince, R. I. T., Adhitya, A., Murdock, J., & McCabe, K. (2000). Marine seismic surveys-a study of environmental implications. *Australian Petroleum Production and Exploration Association Journal, 2000*, 692-708.

McDonald, M. A., J. A. Hildebrand, S. M. Wiggins. (**2006**). Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicholas Island, California. Journal of the Acoustical Society of America **120**, 711-718.

National Research Council (NRC). (1994). *Low-frequency sound and marine mammals: Current knowledge and research needs.* Washington, DC: The National Academies Press.

National Research Council (NRC). (2000). *Marine mammals and low-frequency sound*. Washington, DC: The National Academies Press.

National Research Council (NRC). (2003). *Ocean noise and marine mammals*. Washington, DC: The National Academies Press.

National Research Council (NRC). (2005). *Marine mammal populations and ocean noise: Determining when noise causes biologically significant events*. Washington, DC: The National Academies Press.

Nowacek, D. P., L. H. Thorne, D. W. Johnston, and P. L. Tyack. (2007). Responses of cetaceans to anthropogenic noise. Mammalian Review, 37(2), 81-115.

Popper, A. N. and P. L. Edds-Walton. (1997). Bioacoustics of marine vertebrates. In M. J. Crocker (ed.), *Encyclopedia of Acoustics, Vol. IV*, (pp. 1831-1836), (John Wiley and Sons, New York).

Popper, A. N., J. Fewtrell, M. E. Smith, and R. D. McCauley. (2004). Anthropogenic sound: Effects on the behavior and physiology of fishes. *Marine Technology Society Journal 37*, 35-40.

Richardson, W. J., Greene, C. R., Malme, C. I., & Thomson, D. H. (Eds.). (1995). *Marine mammals and noise*. New York: Academic Press. 576 pp.

Samuel, Y., S.J. Morreale, C.W. Clark, C.H. Greene, and M.E. Richmond. (2005). Underwater, low-frequency noise in a coastal sea turtle habitat. *Journal of the Acoustical Society of America 117,* 1465-1472.

Schusterman, R. J., Kastak, D., Levenson, D. H., Reichmuth, C. J., & Southall, B. L. (2000). Why pinnipeds don't echolocate. *Journal of the Acoustical Society of America 107*, 2256-2264.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr., C. R., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, W. J., Thomas, J. A., and Tyack, P. L. (2007**)**. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals 33(4),* 411-522.

Tavloga, W. N. (ed.). (1964). Marine bio-acoustics (Pergamon Press, New York). 413 pp.

Tyack, P. L. (1998). Acoustic communication under the sea. In S. L. Hopp, M. J. Owren, & C. S. Evans (Eds.), *Animal acoustic communication* (pp. 163-220). Berlin: Springer-Verlag.

U.S. Marine Mammal Commission (MMC). (2006). Advisory Committee on Acoustic Impacts on Marine Mammals, Report to the Marine Mammal Commission, February 2006. 136 pages.

Wartzok, D. & Ketten, D. R. (1999). Marine mammal sensory systems. In J. E. Reynolds II & S. A. Rommel (Eds.), *Biology of marine mammals* (pp. 117-175), (Smithsonian Institute Press, Washington D.C.).

Appendix I. Roles and responsibilities of U.S. federal agencies relative to anthropogenic sound and the marine environment [and agency representatives contributing to this report].

Marine Mammal Commission (MMC)

[Representatives to the Task Force: Drs. Robert Gisiner and Timothy Ragen]

MMC is mandated to ensure the protection and conservation of marine mammals and the ecosystems of which they are a part. Human activities pose a variety of threats to the marine ecosystem, such as fishery impacts, contaminants, sound, harmful algal blooms and dead zones, habitat loss, and climate change. Although other threats are undoubtedly more serious than sound, the magnitude of the risks posed by sound appears to be growing while the nation, and the world, remains uncertain about the appropriate course of action to mitigate those risks. Much remains to be learned, not only about sound sources but also about the biological significance of sound to marine mammals and marine mammal populations. Development of national capability in ocean acoustic sensing and monitoring is essential to promote safe ocean resource exploitation and management, while also protecting and conserving the marine environment.

Minerals Management Service (MMS)

[Ms. Jill Lewandowski and Ms. Judy Wilson]

MMS, a bureau in the U.S. Department of the Interior, is the Federal agency responsible for managing the nation's natural gas, oil, non-energy minerals and alternative energy resources on the outer continental shelf. MMS currently administers close to 7,500 active leases on 40 million acres and collects more than $8 billion per year in revenues from Federal leases. In implementing its programs, MMS is charged with ensuring that activities it regulates are conducted in a technically safe and environmentally sound manner. For activities which introduce sound into the environment (e.g., seismic surveying, drilling, production), MMS uses the best available information (rather than scientific certainty) to analyze impacts and design mitigation and monitoring requirements and regulations that reduce or eliminate the potential for effects. MMS also funds and conducts research necessary to help fill important information gaps. These collective efforts allow MMS to play an integral role in improving our understanding of acoustic impacts and advancing management systems while maintaining an energy program important to the nation.

National Oceanic and Atmospheric Administration (NOAA)

[Drs. Brandon Southall (Task Force Lead) and Amy Scholik-Schlomer]

NOAA has broad and numerous mandates under various federal laws (*e.g.*, Endangered Species Act, Marine Mammal Protection Act, Magnusson-Stevens Fishery Conservation and Management Act, National Marine Sanctuaries Act, and National Environmental Policy Act) include studying and managing protected marine species. NOAA thus has both regulatory responsibilities and science and technology leadership requirements with regard to the marine environment and offshore resource management, creating broader responsibilities for this issue than most, if not all, other federal agencies. NOAA applies the relevant statutory authorities, cited above, in managing the adverse effects of noise on marine life, and does so using the best-available scientific information.

NOAA also conducts research or supports external research efforts strategically directed toward increasing scientific understanding of this and similar marine resource issues. NOAA remains focused on understanding and mitigating the adverse effects of intense, acute noise sources on marine life, but NOAA is increasingly concerned with chronic, long-term sources of anthropogenic sound input to the ocean and their potential impact on overall marine ambient noise. While much of NOAA's focus on the marine sound issue has involved marine mammals, NOAA is increasingly aware of and dealing with impacts on fish, sea turtles, and even some marine invertebrates.

National Science Foundation (NSF)

[Dr. William Lang and Ms. Holly Smith]

NSF is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF is the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. Another essential element in NSF's mission is support for science and engineering education, from pre-K through graduate school and beyond. NSF funds proposals on basic research and technology that advances basic research. There are few limitations on topics and intense competition on quality. Proposals directed to NSF can address the full range of marine acoustic subjects, including design of new acoustic instruments and research on marine sound, the use of sound by marine organisms, and the effects of sound on the marine environment. Proposals directed to NSF also include proposed use of active sound sources as a research tool. In contrast to directed research programs in other agencies, the extent and topics to which NSF funds research on acoustic issues is largely dependent on the response of the greater academic community. However, in support of vessel operations, NSF can 'direct' limited funds to assessing and mitigating impacts of operations.

U.S. Army Corps of Engineers (ACE)

[Dr. Joseph Wilson]

U.S. Coast Guard (USCG)

[Dr. Jon Berkson]

USCG is one of the five Armed Services of the United States and the Nations' primary maritime law enforcement agency. In addition, USCG provides a wide range of maritime safety, security, and environmental protection services. The Coast Guard protects vital interests of the United States from foreign and domestic threats, both natural and man-made, and serves in America's ports and inland waterways, along the coasts, on international waters, or in any other maritime region where the United States' interests are at risk. USCG is a military, multi-mission, maritime service that possesses a unique blend of humanitarian, law enforcement, regulatory, diplomatic, and military capabilities. These characteristics are underscored by the Coast Guard's five fundamental roles: maritime security, maritime safety, protection of natural resources, maritime mobility, and national defense.

U.S. Department of Energy (DOE)

[Ms. Susan Gregerson and Mr. John Prydol]

DOE conducts research and development to support the domestic petroleum industry in developing new technologies and operating practices that are more environmentally-sensitive and cost-effective for both offshore and onshore oil and natural gas development. This R&D is focused on high-risk, high-potential petroleum resources and technologies that are not being addressed by the domestic industry.

U.S. Department of State (DOS)

[Mr. John Field and Ms. Maggie Hayes]

DOS is charged broadly with developing and implementing U.S. foreign policy and advancing U.S. interests in the international community. Issues involving the marine environment and its resources are handled through the Department's Bureau of Oceans, Environment, and Science (OES). The bureau promotes transformational diplomacy through advancing environmental stewardship, encouraging economic growth, and promoting social development around the globe to foster a safer, more secure and hopeful world. The Department's specific interest in anthropogenic sound lies in effective communication of U.S. activities to the international scientific and maritime communities, and assisting U.S. technical agencies in securing bilateral or multilateral cooperation as appropriate on particular science and technology issues.

U.S. Fish and Wildlife Service (USFWS)

[Ms. Diane Bowen and Mr. Martin Kodis]

USFWS was given authority to implement the Marine Mammal Protection Act for the conservation and management of sea and marine otters, walrus, polar bear, 3 species of manatees, and the dugong. Several of these are also listed under the U.S. Endangered Species Act (ESA) and the Service has a responsibility to manage and protect these species in accordance with the ESA. All of these animals spend the majority of their life in the ocean environment and, therefore, all are potentially impacted by anthropogenic sound in that environment. Although we are gaining more information about potential acoustic impacts on each of these trust species, there are still many unanswered questions surrounding the effects of various acoustic-related activities and possible ways to minimize any adverse effects. In addition, each of these species has unique needs and behaviors that differ and must be studied and addressed accordingly.

U.S. Department of Defense, U.S. Navy (USN)

[Dr. James Eckman (Office of Naval Research), CAPT Robin Brake (Office of the Deputy Secretary of the Navy, Environment and Installations), Dr. Robert Winnokur (U.S. Department of Defense, Joint Chiefs of Staff), and Dr. Augustus Vogel (U.S. Department of Defense, Office of the Oceanographer of the Navy)]

The **Navy's** mission, established in Title 10 of the U.S. Code, is to be continually ready to support the U.S. national interest with prompt and sustained combat operations when directed. This includes ensuring the free use of the high seas, and maintaining continued maritime superiority. In order to achieve this mission, the Navy must engage in at-sea anti-submarine warfare training using active sonar technologies. Military sonar use has been implicated in marine mammal mass stranding events. The Navy is

interested in determining the impacts of anthropogenic sound on marine mammal populations so that readiness and operational needs are properly balanced with the service's responsibility to protect the marine environment in which it operates. While active sonar is the primary concern, other sources such as ship and explosive noise are of concern as well.

Appendix II. Detailed summary of current federal science and technology effort in each of five subject areas regarding anthropogenic sound and marine life.

(1) Sound Sources & Acoustic Environment – U.S. Government (USG) Efforts to Date

Assessments of potential impacts rely heavily on measurements and modeling of the source characteristics of different anthropogenic sound sources and how sounds travel (propagates) through the marine environment. Sound frequency, directivity (radiation) pattern, duration, and environmental conditions (*e.g.*, bathymetry, depth, temperature, salinity, and bottom type) can be as or more important as the source level in determining exposures. Yet as complex as these subjects are, they are arguably the best-understood aspects of the overall issue of how anthropogenic sound affects marine life.

Sound propagation measurements and modeling capabilities to predict sound fields around specific sources are generally advanced. Validated standard models are available for most types of sound sources (natural and anthropogenic) and environmental/bathymetric conditions (for example see http://oalib.hlsresearch.com/).

Most anthropogenic sound sources are also reasonably well-known, especially those used in active sonar and communication systems for military, research, and commercial applications. Sources used in geophysical research and exploration (*e.g.*, seismic airguns) are characterized in great detail for the desired, downward-focused, low-frequency signals, but horizontal and higher-frequency output has generally been ignored. Other sounds produced as a by-product of their intended function, such as explosives, pile-driving, and large vessel sounds, are also less well-characterized, though ongoing or planned efforts by the relevant agency(s) or industry(s) appear likely to resolve most uncertainty about these sources in the near future. The one significant exception to this trend appears to be large vessel sounds and their contribution to marine ambient noise.

Sound production characteristics for most marine animals are relatively poorly known. Certain species, such as the bottlenose dolphin, have been intensely studied both in the field and in the laboratory and are fairly well-understood, but the sound production features of many marine species remain completely unknown. There has been a varying level of effort to measure sound output characteristics of marine animals, driven largely by interests in either emulating the animals' biosonar capabilities or in listening for their sounds to detect and identify them.

(1) Sound Sources/Acoustic Environment – USG Efforts to Date

USN	MMS	NOAA	NSF	USFWS
- Highly calibrated measurements of sounds produced by many military sound sources in water; - Development, validation, and standardization of sophisticated sound propagation models; - Measurements of biosonar characteristics of various cetaceans (dolphins and porpoises) - Acoustic signal characteristics (other than biosonar) in various marine mammals and fish; - Spectrogram correlations and neural network detection.	- Source characterization of seismic airguns and ambient noise measurements during scientific research; - Measurements from field verification of geophysical survey technologies other than airguns.	- Passive acoustic sensor deployments in Stellwagen Bank and Channel Islands National Marine Sanctuaries; - Recovery and analysis of archived USN acoustic measurements for studying trends in ambient noise; - Comparative measurements of ambient noise in areas of variable industrial activity; - Source levels of humpback whale vocalizations; - Blue whale vocalization characteristics; -Development of sound field visualization software.	- Field measurements and modeling efforts on acoustic output from high-intensity, short-duration sound sources (airguns, boomers, and sparkers) used in geophysical research (most often through interagency support and enhanced NEPA analyses)	- Coordinate and review studies to assess sound sources within and the acoustic environment of West Indian manatees

(2) Baseline Biological Information (Physiology, Distribution, & Abundance) – USG Efforts to Date

Another key element in assessing potential impacts of sound on marine life is understanding the anatomy/physiology and presence/abundance of living marine resources. Specific information is needed on the temporal and spatial distribution for selected species, including nominal feeding, breeding/spawning, diving, migrating, habitat utilization patterns, and interactions within ecosystems. Certain species and areas are reasonably well known, and predictive animal distribution models based on environmental features are advancing rapidly. However, more often than not, an individual or organization planning a sound-producing activity may find that the available baseline data are insufficient to provide sufficient confidence in quantitative risk-assessment. This can lead to costly, time-consuming efforts to intensively survey the area of interest before the planned activity can proceed. The action proponent then must undergo the expense and delays associated with contracting survey experts to collect the necessary data.

These baseline biological data requirements generally fall within the scientific and management obligations of resource management agencies (*i.e.*, NOAA and USFWS) and are obtained by directed surveys of populations or management stocks (*e.g.*, marine mammal ship-based line-transect surveys, or fisheries stock assessments). However, an increasing source of baseline biological information is environmental compliance monitoring supported by other federal agencies involved in the marine sound issue (particularly MMS and USN). This has created a *de facto* set of data of potentially great value to all agencies with shared needs regarding risk assessment. However, this resource is currently not centrally archived in a standardized format for access by the resource mission agencies, other affected agencies, or the concerned public.

Recent advances in predictive modeling and the use of acoustics (passive and active) as a research tool are producing additional, high-quality baseline data to support environmental risk assessment. Biological information related to hearing and other physiological responses to sound are discussed in the subsequent section (3).

(2) Baseline Biological Information – USG Efforts to Date

NOAA	USFWS	MMS	USN	MMC	NSF
- Marine mammal, fisheries (including various fishes and invertebrates such as shrimp, crab, lobster), sea turtle, and other stock assessments; - Habitat and ecosystem modeling development and validation; - Baseline research on marine mammal anatomy/physiology; - Integration of passive acoustics in marine mammal stock assessments; - Blood nitrogen levels during diving in bottlenose dolphins.	- Polar bear, walrus, sea otter, and manatee abundance, distribution, habitat, and baseline anatomy & physiology; - Coordination and review of other studies that assess baseline biological information on these species.	- Directed and pilot studies to assess baseline behavior and impacts of acoustic (seismic) exposure on sperm whales; - Long-term study of bowhead presence and migration through the Alaskan Chukchi/Beaufort Sea; - Measurements of bowhead feeding ecology; - Technological improvements to marine mammal survey and tracking methodologies for large whales and belugas; -Behavioral ecology of bowhead, gray, sperm, and beluga whales; - Distribution of North Pacific right whales in North Aleutian Basin.	- Cetacean distributions and density at USN ranges; - Development of acoustic and satellite tagging technology; - Baseline data on cetacean immune systems; - Living marine resources information systems development; - Cetacean vocalization recording and identification.	- Western Pacific gray whale research; - Morphological identification of beaked whales; - Analysis of statistical power in predicting population trends.	- Secondary information generated from marine process studies and seismic cruise monitoring efforts.

(3) Effects of Sound (Criteria and Thresholds) – USG Efforts to Date

Understanding the type, magnitude, and consequences of effects from sound exposure is the crux of assessing the relative importance of anthropogenic sound as a potential stressor on marine life. Ideally, information would be available regarding normal patterns of hearing/behavior and how exposure to sound induces various effects with sufficient certainty to support science-based exposure criteria. There has been increasing effort to quantify direct effects of exposure in a few species, and a limited effort to address the challenging subjects of long-term and/or cumulative impacts of chronic noise exposure. However, this remains well beyond the scope of current understanding. With the current lack of data on acute effects as well as longer-term chronic impacts, it is difficult to objectively consider the overall magnitude of the potential problem and determine the appropriate level of federal response.

The past decade has seen some progress in our basic understanding of acoustic communication and hearing processes in a limited number of marine mammals, fish, invertebrates, and sea turtles, increasingly through the use of electrophysiological methods (which measure neural signals as a means of estimating hearing sensitivity). This has largely been through funding from USN, though NOAA has recently supported

some work in these methods and novel behavioral techniques to measure hearing. However, the hearing of many thousands of marine species remains untested and sample sizes for all species are generally very small, limiting efforts to establish statistical hearing norms within a population. The direct measurements that have been made of the effects of sound on hearing functions in perhaps a dozen different marine mammal species (generally those typically held in captive settings such as bottlenose dolphins and California sea lions) have demonstrated simultaneous interference with ("masking") hearing, as well as residual effects of exposure, such as temporary threshold shifts (TTS) in hearing sensitivity. Additionally, extensive effort has been devoted to determining the risks from impulsive sounds (*e.g.*, explosions and airguns) and to determining the physiological effects of low frequency sound. These studies have measured direct effects on hearing systems as well as the likelihood of other non-hearing physiological effects (*e.g.*, tissue or airspace resonance, vestibular (balance) effects, and neurological effects).

The establishment of general quantitative metrics for behavioral effects is proving to be a more daunting task, due to the complex and variable nature of changes in behavior. Current "exceptions" to general hearing-based models for estimating behavioral effects all tend to revolve around reactions that are unique to a species or limited taxonomic group, such as the sensitivity of harbor porpoises to acoustic harassment devices and the apparent sensitivity of beaked whales to mid-frequency tactical sonar sounds in certain conditions. There is rapidly increasing realization among the academic research community and the federal agencies that well-controlled, quantitative measures of behavioral response may be most effective in identifying and mitigating adverse behavioral effects from anthropogenic sound. The cost and complexity of experimental methods to provide specific exposure-response data, such as controlled exposure experiments (CEEs), argue for some level of inter-agency collaboration, which is beginning to occur as well (*e.g.*, the ongoing joint NOAA-USN Behavioral Response Study (BRS) in the Bahamas).

Cox *et al*. (2006) consider the various hypotheses for mechanisms underlying the apparently strong and in some cases lethal reactions of beaked whales to mid-frequency active sonar in certain conditions. A number of the potential explanations involve damage to non-auditory tissues. USN (and to lesser extent NOAA) has directed efforts to measure how sound exposure may affect non-auditory tissues either directly or secondarily through changes in behavior, although current understanding of these phenomena is very limited.

Similarly, studies of the cumulative and/or long-term effects of multiple exposures to persistent or recurrent sources of manmade sound have been few, despite their importance. As difficult as it is to adequately understand the effects of a single exposure event, such an approach is insufficient to characterize the extent of real-world effects in which animals may have many exposures to a diversity of sound sources of the course of months or years. The cumulative impacts of exposure to chronic acoustic sources could have greater potential impacts on populations of marine organisms than intense, discrete exposures. Despite the recognized need for assessing cumulative and/or long-term effects, relatively few specific efforts have been directed toward these matters.

(3) Effects of Sound (Criteria and Thresholds) – USG Efforts to Date

USN	NOAA	MMS	MMC	USFWS
- Hearing sensitivity measurements and masked thresholds in marine mammals and sea turtles; - Evoked potential hearing technology development; - Behavior response/controlled exposure studies in marine mammals and fish; - Tagging technology development; - Marine mammal safety criteria (TTS); - Auditory effects of sonar on marine mammals; - Nitrogen bubble formation in odontocetes.	- Evoked potential hearing measurements in marine mammals; - Development of rapid behavioral hearing measurements in marine mammals; - TTS measurements cetaceans; - Effects of blast trauma on sea turtles; - Passive acoustic deployments to investigate marine mammal distribution and vocal trends as a function of anthropogenic activity; - Efforts to quantify overall increases in marine ambient noise.	- Numerous noise/disturbance studies since early 1980s (seismic, production, drilling, explosive removal) on marine mammals; - Assessments of effects from oil/gas industry noise on migratory patterns of bowhead whales; - Integrating recent and long-term studies with marine mammals, bearing on cumulative and/or long-term exposure.	- Contracted scientific review of agency-generated environmental impact statements and NEPA-related documents.	- Assessed manatee behavior in the absence/presence of boats in protection areas; - Coordinated and reviewed other studies that assess manatee behavior in response to vessels.

(4) Monitoring and Mitigation – USG Efforts to Date

Concern about the potential environmental effects of sound-producing activities has led to the implementation of various mitigation measures and verification monitoring intended to reduce environmental risk. These requirements have added considerable cost to NSF and ONR research efforts and agency mission-critical activities for USN, MMS, and others. Such costs could reasonably be considered part of a new cost structure for doing business, as for other environmental compliance actions, provided that the required monitoring and mitigation was empirically shown to be effective in reducing actual environmental risk. This is not the case.

To the best of our knowledge, none of the currently required monitoring and mitigation measures have been sufficiently verified and validated for effectiveness, nor have alternatives been adequately explored to assess potential increases in effectiveness or reductions in cost and loss of agency mission capability. For instance, sound source "ramp-up" (where the output level is gradually increased) is a widely imposed practice, founded on the principle that animals potentially at risk from a sound will be given sufficient time to move away. However, despite the cost of implementing this mitigation, there has never been a demonstration that it works as intended. Similarly, some level of visual survey effort is usually agreed upon, at considerable cost (both in time and resources) to the activity being monitored, even though visual monitoring under the best of conditions may detect less than 50 percent of most marine mammals and only 1-10 percent of some deep-diving mammals (see Barlow and Gisiner, 2005). In poor weather and at night those percentages are reduced to effectively zero. Promising new monitoring solutions such as passive acoustic detection, radar-based marine mammal detection, active acoustic detection of fish schools or marine mammals, and the use of underwater gliders or unmanned underwater and aerial vehicles as sensor platforms have received some minor levels of research funding but remain important areas of future research in

developing and validating the effectiveness of a more multi-modal approach to the detection of marine life for risk mitigation and effects monitoring.

The area of mitigation and monitoring has seen perhaps the broadest overall effort of U.S. federal agencies. This is not surprising, given that various federal laws, and increasingly lawsuits directed at regulating agencies, require action agencies to apply mitigation measures. While regulatory agencies have attempted to apply the available scientific information to develop science-based mitigation requirements, legal actions directed at process tend to increase regulatory burdens independent of research efforts. Again, these efforts are generally poorly (if at all) supported by direct empirical measures of the justification and/or efficacy of the mitigation and monitoring measures being required or applied. Nevertheless, most of the principal federal agencies dealing with the marine sound issue have exerted considerable effort to identify marine life around sound-producing operations and develop mitigation measures to reduce potential impacts.

(4) Mitigation and Monitoring – USG Efforts to Date

USN	MMS	USFWS	NOAA	NSF
- Electronic tag development; - Radar monitoring capability development; - Passive acoustic technology development on gliders; - Marine mammal monitoring on ranges technology development; - A4I-SIPS (Scaled improvement performance sonar); - Active acoustic sensing of marine mammals or fishes; - Critical habitat predictive modeling capability development	- Passive acoustic monitoring for marine mammals, including hardware applications and improved signal processing; - Research and development of acoustic tagging technology; - Analysis of observer reports.	- Monitoring and mitigation measures developed in conjunction with incidental take for walrus and polar bears; - Assessing the effectiveness of manatee mitigation measures; - Coordinate and review other studies that assess effectiveness of mitigation measures.	- Right whale detection and reporting system using passive acoustics to detect and localize whales for mitigation of ship-strikes.	- Monitoring &mitigation conducted for all research cruises using airguns; - Support of instrument purchases and engineering proposals for monitoring and mitigation measurements.

(5) Outreach, Education, and Scientific Peer Review – USG Efforts to Date

The review and dissemination of scientific information to the scientific community, decision-makers, and the general public is a vital step that cannot be overlooked. The effects of anthropogenic sound on the marine environment is a complex issue, often mischaracterized in the popular press, that is confusing to a concerned public presented with widely varying viewpoints on the issue. A key role of federal agencies is to support high-quality subject matter expert peer-review and synthesis of pertinent information (*e.g.*, NRC, 1994, 2000, 2003, 2005). Another important function is making science-based information available in engaging formats to the interested public, teachers, reporters, docents, students, foreign governments, and intergovernmental organizations. Finally, future decisions and discoveries will only be possible with sufficient infrastructure and programs to support undergraduate, graduate, and post-doctoral students working in key areas.

The federal agencies have recognized these specific needs for ensuring that high-quality scientific information is obtained, published, made available, and interpreted

appropriately and have supported various actions accordingly (described in detail below). Most of the federal agencies involved here have contributed significantly in supporting various technical symposia, panels, and workshops on a wide variety of important scientific topics. The agencies recognize the need and value of supporting the highest-quality levels of peer-review for research efforts followed by considerable public outreach and education via school programs, lecture series, and on-line information. Finally, many of the federal agencies here have contributed support, information, and/or expertise to the Discovery of Sound in the Sea (DOSITS) website (www.dosits.org), which provides a wealth of information at various levels of complexity.

(5) Education, Outreach, and Scientific Peer-Review – USG Efforts to Date

NOAA	MMS	USN	NSF	USFWS	MMC	DOS
- Support of international symposia on large vessel sound and marine life; - Technological and economic considerations of quieting large commercial vessels; - Support of scientific panels developing noise exposure criteria for marine mammals, fish and sea turtles; - Partial support of DOSITS educational website; - National lecture series on ocean acoustics; - Partial support of several National Research Counsel panels on marine noise; - Bioacoustic information integrated into NOAA online educational materials.	- Literature review contribution for Marine Mammals and Noise (1994) NRC report; - Support of scientific peer reviews, conferences and symposia; - Partial support of fish bioacoustics workshop.	- Web-based library development; - Field guide for stranded animals; - Graduate and post-doctoral education through the bioacoustic oceanography summer workshops; - Partial support of the DOSITS website; - Periodic open program reviews (ECOUS meetings); - Support for conferences on marine mammal biology and acoustics; - Auditory evoked potential workshops.	Partial support of DOSITS website; outreach and community meetings on specific projects; extensive peer review for proposals and peer-reviewed publications; support for technical meetings and workshops	- Various outreach and educational materials on polar bears, walruses, sea otters, and manatees.	- Congressionally-commissioned FACA panel on marine mammals and sound; - Beaked whale symposium and related journal issue.	Transmission of salient research findings and literature on marine acoustics in response to United Nations requests; ongoing assistance to USG agencies interested in multilateral and bilateral research efforts

Appendix III. Detailed summary of prioritized science and technology for U.S. federal agencies in each of five subject areas regarding anthropogenic sound and marine life.

The Task Force undertook the task of identifying specific research and development needs in each the five specific subject areas. It then segregated these needs into an inter-agency view of those of highest, high, and moderate priority. This process was undertaken for each subject category individually, and the resulting prioritized actions are given in detail in this appendix. Following this process, the task force synthesized and considered these priority recommendations across all subject categories and summarized categories of the most important near and long-term actions in order to identify effects of exposure, develop technical capabilities, advance monitoring and mitigation, and improve data archive and analysis capacity. This secondary process is described in Chapter 3, culminating in the task force recommendations in Chapter 5.

(1) Sound Sources and Acoustic Environment – Prioritized USG Needs

Acoustic characterization of specific sound sources is relatively advanced, though there are certain existing and emerging sources that require calibrated measurement. Specific agencies or industries deploying these sources should likely bear the burden of ensuring such measurements (*e.g.*, as NSF has recently done with airgun seismic sources). Where they are made, source characterizations should include full-azimuth measurements, careful reporting of all calibrations, and wide-frequency bandwidth measurements. There is a particular need for source characterization measurements for new and emerging sources, as well as those operated in areas such as the Arctic that are experiencing rapid changes in both climate and human activity using such sources.

Regarding the larger and more difficult matter of characterizing marine ambient noise, current knowledge is much poorer and the needs are consequently more daunting. The question of whether there is an historical and ongoing change in ambient noise arising from overall increases or changes to the diverse array of anthropogenic sound sources, and, if so, what effect it may have on marine life, is a broad, complex matter. The issue of non-directional ambient noise is sufficiently non-specific to a particular source or operation that it arguably falls outside any of the mandated requirements of any of the federal agencies other than NOAA. NOAA will require external expert assistance in dealing with this issue (which has in fact already occurred in the form of NOAA-ONR collaboration on recovery of archived USN data for ambient noise analysis).

(1) Sound Sources and Acoustic Environment – Prioritized USG Needs

Subject Category	Specific Science/Technology Need(s)	Relative Priority (within subject)
(1) Sound Source & Acoustic Environment	- Longitudinal measurements of ambient noise budgets in variable locations (particularly Arctic). - Continued development of passive acoustic monitoring technologies for detecting/characterizing biological sources. - Sound source characterization/verification for icebreakers (Alaskan Arctic) and new classes of large commercial vessels.	**Highest (A)**
(1) Sound Source & Acoustic Environment	- Sound source verification for new wide-azimuth seismic surveys. - Sound source characterization/verification of pile driving of variable types and in variable substrates. - Advancement of shallow-water propagation models for impulsive sound stimuli. - Sound source characterization/verification for oil drilling and production.	**High (B)**
(1) Sound Source & Acoustic Environment	- Development of online sound source library (both anthropogenic and biological sources). - Sound source characterization and (where appropriate) long-term monitoring of: (*a*) offshore LNG terminals; (*b*) wind farm arrays; and (*c*) emerging tidal & wave energy technologies. - Sound source characterization/verification for seismic sources other than airguns.	**Moderate (C)**

(2) Baseline Biological Information (Physiology, Distribution, & Abundance) – Prioritized USG Needs

Determining baseline biological and life history data for marine life generally is beyond the scope of this report, as it is not specific to acoustic issues. There is ongoing and needed work in those areas, of course, much of which is relevant to a complete assessment of the impacts of specific sounds on marine life. What is intended in this section is basic biological information relating specifically to the marine noise issue (perhaps considered "baseline acoustical information") as well as direct information on the effects of noise on hearing, behavior and physiology.

Knowing what marine life is or will be present at a given site of interest is often a limiting factor in terms of planning, assessing impacts, and devising mitigation strategies. Effort to sufficiently sample the marine environment requires agencies to develop common procedures for sensor calibration, standards for how data and metadata are recorded, and processes for shared access to data for other agencies, researchers, and the public. Historically, most or all of this information has been generated by a relatively small scientific community, or was generated by NOAA for resource management purposes. Perhaps for the first time, external sources of quality data may equal or even exceed the pace of data generation by NOAA itself. A similar situation already exists for standard oceanographic data, with USN and others contributing to ocean data archives

maintained by NOAA. A key federal effort could be achieving national data standards, interagency data sharing agreements, and the resources to support a national data archive for ocean biological data comparable to our ocean physical data archives. This data archive should include both direct sampling as well as the validated performance of increasingly-sophisticated habitat modeling efforts. Such an archive would logically be NOAA-led, with considerable data input from agencies – or agency-supported researchers – including USN, NSF, MMS, USCG, and USFWS.

The federal agencies participating in the task force also identified related important data needs on specific baseline physiology, diving, migration, and other life history parameters in order to adequately predict and assess impacts. The task force additionally prioritized needs to investigate certain species, apparently more sensitive species and those in the rapidly-changing Arctic, as noted in the table below.

(2) Baseline Biological Information – Prioritized USG Needs

Subject Category	**Specific Science/Technology Need(s)**	**Relative Priority** (within subject)
(2) Baseline Biological Information	- Expansion/improvement of spatio-temporal measurements of distribution and abundance of marine species (direct measurements integrated with predictive modeling of habitat features). - Develop, standardize, integrate, and maintain online databases of marine mammal distribution, abundance, and movement (it is worth noting the considerable value-added aspect of this action relative to assessing other potential impacts on marine mammals) - Baseline physiological and life history data (including diving/migratory behavior) for "particularly sensitive" species (*e.g.*, beaked whales) and Arctic marine species.	**Highest (A)**
(2) Baseline Biological Information	- Baseline measurements of behavior and movement patterns of other "representative" marine species not listed as Priority A, both short-term (*e.g.*, diving behavior) and long-term (*e.g.*, migratory behavior) - Baseline physiological and life history data for other "representative" marine species. - Develop better baseline data on recruitment, reproduction, and mortality with which to assess long-term/cumulative impacts.	**High (B)**
(2) Baseline Biological Information	- Develop basic assays for stress and immune functions and invest in low level of advancement to diagnostics, as a means of quantifying non-obvious low-level, long term cumulative effects. - Improve tools and technologies (including active acoustics) to measure foraging ecology of "representative" marine species.	**Moderate (C)**

(3) Effects of Sound (Criteria and Thresholds) – Prioritized USG Needs

As discussed, the crux of this environmental issue is determining those specific exposure conditions that result in demonstrated adverse effects of noise exposure. Without such knowledge, it is unclear how much overall attention and/or effort is warranted and which monitoring and mitigation requirements will be effective in a particular sound-producing activity. Consequently, the task force considers a relatively

large number of priority research requirements within this category (see below). These include basic measurements of hearing for untested or underrepresented species, including measures of "absolute" or unmasked hearing thresholds and sound localization capabilities, as well as more sophisticated measurements of auditory masking and noise-induced hearing loss. Of additional pressing importance is the need for objective means of distinguishing between relatively benign effects and the more biologically-significant changes in behavior arising from sound exposure that might lead to serious adverse consequences at the individual and population level. Finally, and while admittedly very challenging and poorly understood, we deemed it very important that science and technology efforts begin seriously addressing cumulative and/or long-term adverse impacts from repeated or sustained exposures, including the potential interactions of noise with other anthropogenic stressors (e.g. chemical contaminants or climate change effects) leading to cumulative adverse consequences for marine life.

(3) Effects of Sound – Prioritized USG Needs

Subject Category	Specific Science/Technology Need(s)	Relative Priority (within subject)
(3) Effects of Sound ***(Criteria & Thresholds)***	- Obtain hearing & effects of noise on hearing measurements for "particularly sensitive" (*e.g.*, beaked whales), Arctic, mysticete cetacean species (various sex/age classes). - Empirical measurements of effects of sound exposure on behavior of "representative" marine species (controlled exposure experiments), particularly for high-intensity sources. - Increase ability to identify biological effects from sound exposure. - Improve/validate exposure noise exposure criteria and policy guidelines. - Measure acoustic perception/localization of biological signals and interference from realistic masking noise.	**Highest (A)**
(3) Effects of Sound ***(Criteria & Thresholds)***	- Obtain/expand hearing & effects of noise on hearing measurements for other "representative" marine species (various sex/age classes). - Develop/expand anatomical modeling.	**High (B)**
(3) Effects of Sound ***(Criteria & Thresholds)***	- Quantify effects of auditory masking at both individual and population levels. - Determine effects of noise on foraging behavior, stress hormones, and immune function (cumulative effects). - Develop techniques to investigate/quantify interaction of noise exposure with other stressors (synergistic effects)	**Moderate (C)**

(4) Mitigation and Monitoring – Prioritized USG Needs

The need to detect and/or characterize the activities of marine life offers tremendous opportunity for rapid growth in tools and technologies valuable to national and international marine resource management. The recognition that current visual sampling methods from surface platforms are have serious limitations to sample highly mobile animals in opaque, three-dimensional environments has led several agencies to explore alternative or supplemental means of detecting and monitoring marine life.

Rapid advancements are occurring in this field, but additional investment and attention is needed to improve sensor technologies, including passive acoustic sensors on various stationary and mobile platforms and advances in various visual, electromagnetic, and other sensors. Many of these technologies have been and will continue to be developed by the USN; they are the logical lead agency on many topics, although some other agencies are interested in advancing and applying these capabilities as well. Depending on internal agency expertise and existing capabilities for basic research, applied research, and end-stage technology development, the path from novel concept to readily-usable technology may require the coordinated efforts of multiple agencies.

Additionally, there is a clear and immediate need for scientific verification of the performance of existing and new mitigation measures, often made more difficult by the lack of clear, observable effects. No current mitigation or monitoring measures offer metrics for detection and classification probabilities, including false alarm rates or performance limitations under conditions of poor weather, darkness, or other variable at-sea conditions. There is a need for some standardization in the process by which mitigation and monitoring requirements are determined for the purposes of reducing acoustic impacts.

Where specific impacts are known, or where sound output serves no particular function but is simply incidental to an activity, there should be particular attention and effort applied to reducing the overall acoustic footprint, weighted against the cost of noise reduction or impairment to the activity of concern (*e.g.*, vessel speed, maneuverability, safety, training efficacy). A further mitigation option (beyond modifying sources or their operation) that should be explored in some conditions (where effects are clearly known and the need to reduce them of known biological significance), is temporal or area restrictions to certain sound-producing activities. Recognizing the substantial challenges, there should also be some level of attention given to mitigation of cumulative and/or long-term impacts, above and beyond the reduction in immediate effects.

(4) Mitigation and Monitoring – Prioritized USG Needs

Subject Category	**Specific Science/Technology Need(s)**	**Relative Priority (within subject)**
(4) Mitigation & Monitoring	- New and improved technologies for identifying, locating, and tracking marine mammals (real-time where possible). - Develop validation and performance metrics for all mitigation measures (detection probability, false alarm rate, coverage per unit time or effort, etc). - Explore alternatives to existing sound sources and/or mitigating technologies to minimize unwanted and unnecessary sound output (*e.g.*, vessel-quieting technologies) or to reduce impacts of specific sources by alterations that do not adversely affect performance (*e.g.*, alternate waveforms). - Explore need for and effectiveness of time/area closures versus operational mitigation measures.	**Highest (A)**
(4) Mitigation & Monitoring	- Improved technologies for identifying, locating, and tracking fish and sea turtles (real-time where possible). - Standardize data-collection, reporting, and archive requirements of marine mammal observer programs; sufficiently analyze existing data and render available to inform future mitigation efforts.	**High (B)**

(4) Mitigation & Monitoring	- Develop performance metrics for monitoring, mitigation, and reporting. - Develop and validate simple decision-making criteria for source shutdown, modification or movement.	**Moderate (C)**

(5) Outreach, Education, and Scientific Peer Review – Prioritized USG Needs

While this category is discussed last, it should clearly not be interpreted as the least important. Rather, the review, dissemination, and general impact of scientific information regarding all areas of the marine sound issue are in many ways among the most important ongoing and future efforts of federal agencies. Federal agencies contributing to this report identified a number of specific needs in terms of peer-review, systematic reviews of available data, capability-development, and general outreach and education. Many of these are consistent with standard or existing practices, whereas others suggest more innovative, proactive approaches than has historically been the case. There is a general sense that all of these subjects will require serious and consistent effort by the federal agencies to ensure that the next generation of scientists and engineers enter and improve this field, and that the general public has open and full access to understandable and scientifically accurate information.

(5) Outreach, Education, and Scientific Peer Review – Prioritized USG Needs

Subject Category	Specific Science/Technology & Other Need(s)	Relative Priority (within subject)
(5) Outreach, Education, & Peer-Review	- Develop a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government, industry, academia, public, educators, media, and environmental groups); Timely peer-reviewed publication of all (unclassified) scientific results. - Periodic national expert panel review of existing scientific data relating to all subject categories.	**Highest (A)**
(5) Outreach, Education, & Peer-Review	- Enhance availability/visibility of educational/outreach materials to the general public through existing mechanisms (*e.g.*, DOSITS website). - Some level of investment in K-12 education (via some established program such as Lawrence Hall of Science) and public information resources at oceanaria, marine reserves, etc.	**High (B)**