Report of the Marine Mammal Commission Consultation

August 4-7, 2003

Future Directions in Marine Mammal Research

Report on the Consultation on Future Directions in Marine Mammal Research

Portland, Oregon
4–7 August 2003

By Randall R. Reeves, Ph.D.
and Timothy J. Ragen, Ph.D.

Marine Mammal Commission
4340 East-West Highway, Room 905
Bethesda, Maryland 20814

31 July 2004

Commission Offices

4340 East-West Highway, Room 905
Bethesda, Maryland 20814
Phone: 301-504-0087 Fax: 301-504-0099
E-mail: mmc@mmc.gov Website: http://www.mmc.gov

Table of Contents

Executive Summary

In August 2003 the Marine Mammal Commission consulted many of the world's leading marine mammal scientists to identify future directions for marine mammal research. The purposes were to (1) identify and evaluate threats to marine mammals; (2) develop research recommendations to further our understanding of such threats and devise methods to address and mitigate them; and (3) generate new creative and proactive approaches for resolving issues related to the conservation of marine mammals and their environment.

The Commission asked participants in the consultation to bear in mind the following points:

- the effects of human population growth and associated economic development;
- the important subsistence and cultural uses of marine mammals;
- the values attributed to marine mammals in addition to resource use; and
- the necessity of an interdisciplinary approach to research.

The consultation steering committee identified the following ten issues or threats to marine mammals and their habitat:

- direct fishery interactions
- indirect fishery interactions
- disease
- contaminants
- harmful algal blooms
- anthropogenic sound
- habitat transformation
- long-term environmental change
- identification of conservation units
- human population growth and demography

Leading scientists prepared background papers for each topic. This report describes in detail the research needed to address each topic. In addition, a compilation of the background papers and an overview of the consultation results will be published in book form to ensure wide dissemination of the recommendations among marine mammal researchers, researchers in related fields, and others interested in marine science, management, and conservation.

The Primary Objective of the Marine Mammal Protection Act

In passing the Marine Mammal Protection Act, Congress found that "... the primary objective of [marine mammal] management should be to maintain the health and stability of the marine ecosystem" (16 U.S.C. 1361 (2)(6)). To that end, the Act (1) provides a framework for managing human activities that may adversely affect marine mammals and (2) requires scientific assessment of the status of marine mammal stocks and the effects of human activities on them.

Progress Under the Marine Mammal Protection Act

Since its passage in 1972, the Marine Mammal Protection Act has significantly enhanced the conservation of marine mammals and marine ecosystems. The California gray whale has recovered, and a number of other large whale species are recovering from whaling-caused declines. Some pinniped species have recovered from reductions in the early to mid-1900s. Annual reported dolphin mortality in the eastern tropical Pacific tuna fishery has decreased from hundreds of thousands to fewer than 2,000 animals. Unintentional bycatch of marine mammals in fisheries and various forms of intentional mortality also have been reduced by orders of magnitude. Agreements between Alaska Natives and management agencies have begun to incorporate Native traditional knowledge and to facilitate Native participation in the management of marine mammals. Many marine mammal stocks are being assessed regularly, providing vital information on their status and on the factors that affect their abundance, life history, and health.

Threats to Marine Mammals and Marine Ecosystems

As far-reaching as the Marine Mammal Protection Act has been, it has not effectively addressed all threats to marine mammals and marine ecosystems. Some widely recognized threats persist and new threats are emerging. Scientists at the consultation concluded that:

- Predicted climate changes will profoundly affect marine ecosystems, particularly in polar regions. A considerable number of pinniped and cetacean species are closely associated with or dependent upon ice-related habitat. Although some populations might increase, others are likely to decrease markedly if ice habitat continues to be lost and they are unable to adapt to the associated physical and ecological changes. Native Alaskans also depend upon sea ice as a platform for hunting, and they will need to adapt to rapidly changing conditions. Species not associated with ice are likely to show changes in distribution and abundance as well.

- Fisheries continue to pose significant threats to marine mammals and marine ecosystems. Fishing gear entangles and kills marine mammals, including the highly endangered North Atlantic right whale. Recent evidence suggests that fishing for tuna by setting on dolphins has subtle effects not previously recognized and that practices once perceived to be benign, or "dolphin-safe," cause stress and thereby reduce dolphin reproduction and survival. The potential for competition between fisheries and marine mammals has led to longstanding and still unresolved controversies about the effects on both the fisheries and the marine mammals.
- Human-caused sound in the marine environment is suspected to be a significant threat to marine mammals, especially cetaceans. A range of human activities introduce sound into the marine environment, including commercial shipping and transportation, oil and gas exploration and drilling, military operations, dredging and coastal construction, scientific research, and fishing. The controversy over the effects of noise has been exacerbated by a lack of information on how marine mammals use sound and how human-caused sound alters their behavior and physiological health.
- Coastal development threatens marine ecosystems, including the marine mammals that live in coastal waters. Human population growth and concentration along Florida's coast, for example, are expected to continue and will further degrade manatee habitat, reducing the potential for recovery and long-term conservation. On the U.S. West Coast, growing human and pinniped populations are already competing for limited coastal resources, including endangered fish populations and space on beaches.
- Disease is a significant factor in the ecology and life history of marine mammals, and it has been implicated in a growing number of marine mammal mortality events. Dramatic examples include the loss of approximately 21,000 harbor seals in Europe in 2001 and the increase in strandings of bottlenose dolphins along the U.S. Atlantic coast in 1987–1988, both from morbillivirus. The long-term population consequences of disease are often difficult to determine, but they are particularly significant for endangered species. Such events also may be indicative of ecosystem degra-

dation due to human activities. For example, scientists have traced Toxoplasma gondii in the waters off central California, introduced via cat feces, to the spread of encephalitis among threatened California sea otters.

- Contaminants can predispose marine mammals to disease by compromising immune function, and they can reduce reproductive success. The cumulative number of registered chemicals has increased from 2 million in 1969 to almost 20 million in 2000. Many of these are finding their way into marine ecosystems, affecting marine mammals and other organisms in ways that can be cryptic but significant to individuals and populations. Resident killer whales in the Pacific Northwest carry contaminant loads greater than those found to adversely affect immune function in experiments with harbor seals. In polar bears, levels of polychlorinated biphenyls are correlated with changes in reproductive hormones and have been suggested as a factor influencing immune function and survival.
- Investigations of recent mass strandings of marine mammals have frequently shown that mortality was due to harmful algal blooms. Some algae produce substances toxic to marine mammals, other marine life, and humans. Algal blooms occur naturally but may be increasing in frequency and severity due to pollution and climate change. In addition, chemicals used in agriculture are being transported into rivers, bays, and coastal waters, causing high levels of algal production and decay that can deplete available oxygen and lead to the formation of large anoxic "dead zones" such as the 7,000-square-mile dead zone at the mouth of the Mississippi River.
- Around the world, some marine mammals face multiple, sometimes overwhelming threats to their existence such as bycatch in fisheries, damming of rivers, contaminants, and destruction of habitat by industrial development. Extinction of China's Yangtze River dolphin (baiji) is imminent. Future prospects are grave for a number of other endangered species and populations, such as the North Pacific right whale, gray whales in the western Pacific, river dolphins in Pakistan's Indus River, the Mediterranean monk seal, and Mexico's vaquita (Gulf of California porpoise).

Are Existing Research and Assessment Strategies Adequate?

The underlying question addressed in the consultation was whether existing scientific programs provide an adequate basis for addressing these and other threats to marine mammals and marine ecosystems. The conclusion was that, in spite of some important scientific advances and management successes, our research and assessment efforts are not adequate to describe the status of most marine mammal stocks or the direct and indirect effects of human activities on them.

Recommended Strategies to Improve Marine Mammal Science

Based on that conclusion, consultation participants identified strategies to enhance the value of science conducted in support of the Marine Mammal Protection Act and related legislation.

Develop long-term, multidisciplinary programs suitably scaled to ecosystem complexity

Our understanding of natural ecosystems has evolved from a simple, static, "balance-of-nature" paradigm to one reflecting their dynamic, complex character. This new paradigm recognizes that ecological change is caused by multiple factors and occurs at a variety of spatial and temporal scales. Under this new paradigm, maintaining the health and stability of marine ecosystems is more complicated conceptually and practically, and the collection of adequate "baseline" information for assessing human impacts is a greater challenge. Still, collection of such information is an indispensable step for assessing human impacts on marine ecosystems, which may be additive or synergistic with natural changes.

Understanding the complex dynamics of multi-faceted, variable marine ecosystems and accounting for diverse human effects will require multidisciplinary research (e.g., oceanography, marine mammal and fishery biology, invertebrate biology, physiology, ecology, and various social sciences). Research must be tailored to match the temporal and spatial scale of complex ecosystem dynamics. Multidisciplinary research and assessment strategies will require better communication and coordination among previously isolated disciplines, expansion of existing monitoring programs, and new programs where none currently exist. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) program exemplifies a comprehensive, long-term research approach that should be continued and replicated to study other marine ecosystems. Well-managed marine protected areas are needed as controls for distinguishing between natural phenomena and anthropogenic effects. A comprehensive national strategy is needed to set priorities for research and assessment, measure progress, and secure support over long periods of time and large areas.

Ensure that population and ecosystem assessment programs are sufficient to inform management decisions regarding current and future threats

Existing assessment efforts are, in many cases, not sufficient to describe the status, trends, and ecology of marine mammal populations, the effects of human activities on them, and the status of the ecosystems of which they are a part. Basic information such as abundance, distribution, mortality, reproduction, and health is lacking for most populations, including some at great potential risk from human impacts. Declines of 50 percent or more could go undetected for some populations. More rigorous assessment programs are needed for marine mammals. They must be appropriately scaled temporally and spatially, and they must involve multidisciplinary approaches that relate marine mammal status and trends to natural and human-altered ecosystem dynamics.

Develop and validate specific, measurable, and robust management standards to achieve the conservation goals of the Marine Mammal Protection Act and related legislation

The existing management standards set to achieve the goals of the Marine Mammal Protection Act and related legislation (e.g., the Endangered Species Act) often lead to controversy because they (1) lack sufficient specificity, (2) cannot be reliably measured for natural populations, or (3) vary as a function of human activities and therefore do not provide stable or suitable references for assessing the effects of those activities. The “optimum sustainable population,” an important standard in the Marine Mammal Protection Act, has been estimated for only a few marine mammal populations. Scientists and managers generally assume the optimum sustainable population to be a fraction of the environmental carrying capacity, but carrying capacity is often unknown for marine mammal populations and, in some cases, may have been artificially reduced by human activities. The Endangered Species Act standards of “jeopardy” and “adverse modification” are similarly vague and controversial. More specific, measurable, and robust standards must be developed and validated to guide management and ensure conservation goals are met.

Identify marine mammal conservation units essential to ecosystem health and function

Marine mammal species often exist as multiple population, stock, or demographic units with limited interaction among them. These units can vary in distribution, status, trends, vital rates (survival and reproduction), life history characteristics, and genetics. Although subtle, such variation implies different ecological and evolutionary roles for these units. Killer whales in the North Pacific, for example, comprise three "ecotypes" that, among other things, differ in foraging strategies. Their respective roles in marine ecosystems clearly differ, depending upon whether they prey on fish, marine mammals, or both. The identification and conservation of such units (whether they are called populations, stocks, subspecies, or ecotypes) are essential to maintain the natural function of healthy ecosystems.

Increase international cooperation in studying and addressing human-related threats

Many threats to marine mammals and marine ecosystems result from the activities of more than one nation. Hence, marine mammals and threats to them are most effectively studied and managed through international cooperation. Cooperative arrangements are needed to address such multinational issues and may range from informal sharing of information on trans-boundary stocks to highly structured, agreements to study and manage resources in international waters (e.g., the Convention for the Conservation of Antarctic Marine Living Resources). Cooperation increases both the knowledge base pertaining to threats to marine mammals and marine ecosystems, and the resources available to study and manage those threats.

Properly assess and communicate the strengths and limitations of the scientific process, including measures of uncertainty that are an essential element of high-quality science

Management decisions made under the Marine Mammal Protection Act and related legislation are to be based upon the "best available science." Due to the difficulty of studying marine ecosystems, that science may be associated with large uncertainty. Accounting for such uncertainty is an essential element of risk analysis and informed decision-making. To reliably guide decision-makers, the best available scientific information must include appropriate descriptions of uncertainty (i.e., how good is the information?). Such descriptions are needed to judge whether scientists will be able to detect significant human-related effects when they occur, and to assess the likelihood that incorrect conclusions could result in either unnecessary regulation of human activities or excessive environmental impacts.

Address ultimate as well as proximate causes of environmental problems

Research on the factors affecting marine mammals and marine ecosystems often focuses almost entirely on proximate rather than ultimate causes. Yet, the majority of threats discussed at the consultation are ultimately related to the size, growth rate, consumption patterns, and behavior of the earth's human population. Some threats may be mitigated or resolved by technological advances, but others are less likely to be resolved technologically and will probably worsen over time. In the foreseeable future, the human species is projected to increase in number and expand its consumption of resources. Maintaining the health and stability of marine ecosystems will require focused long-term research on our own expanding populations, shifts in distribution, and patterns of consumption (i.e., our ecological footprints). Such research is needed to elucidate our impacts and provide guidance on how to limit and compensate for them. It should be linked to long-term assessments of marine biodiversity, ecosystem resilience, the loss of marine habitats through development and contamination, consumption of renewable and non-renewable resources, and human activity in the marine environment.

Risks of Inadequate Research and Management

The Commission asked participants to predict the consequences of not pursuing a more integrated, holistic, and anticipatory marine mammal research agenda. They identified the following:

- The goals of the Marine Mammal Protection Act, the Endangered Species Act, and other environmental legislation will likely not be met, and marine ecosystems will continue to deteriorate.
- Some marine mammal populations will persist, perhaps in large numbers, but many of those that are presently endangered will decline to extinction, as has already occurred for the Steller's sea

cow, North Atlantic gray whale, Caribbean monk seal, and Japanese sea lion.

- Management and recovery efforts will remain reactive rather than proactive and will be confounded by uncertainty and controversy.
- Controversies will be fueled by our inability to distinguish anthropogenic effects from natural phenomena.
- In the absence of clear, unambiguous evidence of human impacts, economic demands will force governments and management agencies to compromise conservation objectives, and this will lead to further losses of biodiversity and ecological integrity.
- Remedies will continue to focus on proximate rather than ultimate causes, and short-term conservation successes will be offset by long-term conservation failures.
- Long-term degradation of marine ecosystems will pose increasing limits on socio-economic alternatives, as has already been witnessed in many over-fished ecosystems.
- Alaska Natives and other indigenous people will be forced to drastically modify, if not abandon, subsistence aspects of their cultures.
- The natural character of marine ecosystems will remain unknown and eventually become unknowable.
- Ultimately, we will pass on to our children a world diminished in its diversity, its options, and its biological wonder.

Implementation of the Recommended Strategies

The Marine Mammal Commission believes that implementation of the strategies recommended above is essential to resolve the threats to marine mammals and marine ecosystems, to avoid the adverse future consequences anticipated by the consultation participants, and to achieve the goal of maintaining healthy, stable marine ecosystems without imposing unnecessary constraints on human activities. Implementation will require an investment beyond current levels of support for research and assessment. However, like preventative medicine, it will prove to be cost-effective over time. Pending Congressional approval and direction, the Marine Mammal Commission is prepared to assist in the implementation of these recommendations.

Who should bear the added cost of the essential research? This question is not a scientific issue, per se but was discussed by consultation participants because it will have a bearing on whether or not the necessary work is done. At present, much of the burden for carrying out such work falls on offices and divisions within the National Marine Fisheries Service and the Fish and Wildlife Service. Their budgets have been and are presently insufficient for implementing the strategies recommended in this report. In general, consultation participants supported the view that the cost of implementing these recommendations should be borne, to a greater extent than currently occurs, by those who stand to benefit financially from activities that pose a threat to marine mammals and marine ecosystems.

Finally, science alone does not and cannot resolve the threats described above. Solutions must reflect societal values, whether cultural, economic, aesthetic, or conservation-oriented. Science provides both knowledge that can shape those values and tools for estimating the costs and benefits of particular courses of action. Proactive science, in particular, can inform the public and decision-makers of the effects of certain actions before social, economic, and environmental crises arise. The Marine Mammal Commission hopes that our efforts to foster thoughtful, carefully directed, proactive science will be useful in preventing such crises, shaping our nation's values, and maintaining the health and stability of marine ecosystems.

Section I. Background and Objectives

Introduction

For many years, the Marine Mammal Commission has encouraged federal agencies and Congress to look beyond immediate crises facing marine mammals and marine environments and take a more far-sighted approach to their management. In the Fiscal Year 2002 appropriation, Congress provided the Commission with funds to explore future research needs of marine mammals and the ecosystems upon which they depend.

In August 2003 the Commission convened a meeting of 65 scientists and managers from around the world (Appendix A) to discuss and debate critical topics concerning the future health of marine mammal populations and their habitat. This report summarizes the discussions at that meeting.

Background

Since 1972, when the Marine Mammal Protection Act was passed, the legal framework for marine mammal protection has developed and evolved, and scientific knowledge about the animals and their environment has increased considerably. The global moratorium on commercial whaling, the development of co-management institutions to oversee subsistence marine mammal hunting in Alaska, and the implementation of a risk-averse procedure for managing incidental mortality of marine mammals in U.S. commercial fisheries represent major achievements. In U.S. waters, some marine mammal populations have made strong recoveries from low numbers in the 1960s and early 1970s. On the West Coast, gray whales and blue whales are considerably more abundant today than they were in 1972, as are elephant seals, California sea lions, and harbor seals (see Appendix B for scientific names of species). On the East Coast, gray seals have returned to breed in areas where they were absent for almost a century; humpback, fin, and minke whales are sufficiently common and predictable to support a firmly established whale-watching industry; and manatee numbers have increased in the southeastern United States. In northern Alaska, some populations of marine mammals remain vital to the subsistence cultures of Native hunting communities, and the bowhead whale is making an impressive recovery while continuing to provide sustenance and social cohesion to Alaska Eskimos.

Such successes represent only part of the story, however. The challenge of conserving marine mammal populations and marine ecosystems becomes increasingly difficult as our own population increases and as we extract ever more resources from marine ecosystems. Environmental changes are altering marine and terrestrial habitats at an alarming scale and rate, possibly threatening the survival of species such as the polar bear. The question of whether commercial whaling should occur and under what kind of management regime remains highly controversial. Although the scale of marine mammal mortality has been reduced in U.S. waters, hundreds of thousands of marine mammals continue to be killed annually in international and foreign waters. Large die-offs of manatees, dolphins, and seals in recent years have drawn attention to the possibility that we are literally poisoning the oceans, whether through the release of toxic chemicals, the transmission of novel pathogens, or the unintended enrichment of coastal waters with agricultural runoff and human waste. Noise associated with ship traffic, offshore oil and gas development, military operations, and marine exploration degrades the quality of marine mammal habitat. Recent evidence suggests that whales, dolphins, and porpoises can die as a result of exposure to certain intense underwater sounds. Some endangered marine mammal species in U.S. waters (e.g., North Atlantic right whales, Hawaiian monk seals, and possibly North Pacific right whales) are not recovering, and populations of several other species (e.g., Steller sea lions, sea otters, and harbor seals in certain regions of Alaska) have recently experienced rapid, unexplained declines.

The Marine Mammal Protection Act embodies a strong national consensus that populations of marine mammals should be maintained at optimum levels to help ensure the integrity of marine ecosystems. As acknowledged in the Act and as demonstrated repeatedly since its enactment, durable solutions to marine mammal problems must be rooted in solid scientific knowledge and understanding. In its oversight role of federal marine mammal research and management programs, the Commission frequently advises the Administration and Congress. Following the provisions of the Marine Mammal Protection Act, the Commission emphasizes anticipatory, proactive approaches that would inform managers and decision-makers and help them avoid the all-too-common reactive, crisis-driven pattern of response. Crisis-driven approaches are generally expensive and provide few options.

In contrast, far-sighted, comprehensive decision-making is both cost-effective and flexible, providing options that benefit living resources, habitat, and society at large.

Objectives

The goals of the consultation were to identify current and future management needs and the research necessary to address them in a proactive manner. In doing so, participants were urged to bear in mind the following points:

- the effects of human population growth and associated economic development;
- the importance of subsistence and cultural uses of marine mammals;
- the values attributed to marine mammals in addition to resource use; and
- the necessity of an interdisciplinary approach to research.

The specific objectives of the consultation were as follows:

- to identify and evaluate threats to marine mammals;
- to develop research recommendations to further our understanding of such threats and devise methods to address and mitigate them; and
- to generate new creative and proactive approaches for resolving issues related to the conservation of marine mammals and their environment.

Meeting Organization, Procedures, and Agenda

The Commission organized the consultation around a meeting of experts to evaluate background papers and formulate research advice. A steering committee (Appendix A) was convened in August 2002 to develop terms of reference for the consultation, choose topics and authors for the background papers, select invited participants, and plan the meeting of experts. John E. Reynolds, III, Chairman of the Commission, and Timothy J. Ragen, Scientific Program Director, co-chaired the steering committee.

The steering committee identified 11 topics to be addressed, ten of which were summarized by background papers (Appendix C). The eleventh topic – "dead zones" in the marine environment – was not covered by a background paper because of a scheduling problem. The papers were circulated to all participants immediately prior to the meeting. Two additional topics not covered by background papers (in addition to dead zones), but discussed during the meeting, were ship strikes (of particular importance to North Atlantic right whales and manatees) and management problems related to increasing (recovering) marine mammal populations. Although the primary goal of the consultation was to discuss and identify research priorities, research and management are closely linked and, therefore, this report includes occasional reference to management.

The meeting of experts was held in Portland, Oregon, 4–7 August 2003 (see Appendix D for the agenda) and was chaired by John Reynolds. Authors of background documents gave plenary presentations on their topics during the first three mornings. Each presentation was followed by a brief plenary discussion. The afternoons were then devoted to facilitated working group sessions in which the topics for that day could be discussed in depth. Composition and procedures of the working groups varied from day to day. Summaries of the findings of each working group were presented at early morning sessions on days two, three, and four. On the fourth day, much of the morning was devoted to plenary discussions of ship strikes and the problems associated with growing marine mammal populations.

This report and a separate report to Congress were drafted by Randall R. Reeves and Timothy J. Ragen with assistance from steering committee members and then reviewed and approved by the Marine Mammal Commission. This report is a synthesis of discussions at the meeting. Participants did not attempt to negotiate specific language of recommendations and major research needs for each topic. They were not asked to rank the threats discussed at the meeting. Such ranking would require consideration of the nature, geographic scale, current level of knowledge about, and difficulty of resolving a given threat. The authors of this report identified the primary themes that emerged from the discussions of each topic and attempted to summarize them. The Commission circulated the draft report to all participants but did not seek consensus on each point.

Acknowledgments

The Commission and steering committee gratefully acknowledge the following:

John R. Twiss, Jr., and Robert H. Mattlin, both former Executive Directors of the Marine Mammal Commission, for their vision in conceiving of the workshop, obtaining the necessary funds, and helping with the initial planning of the consultation;

Whitney Tilt and the National Fish and Wildlife Foundation for administering funds on behalf of the Marine Mammal Commission and making logistical arrangements for all stages of the consultation; and

Tony Faast and his team of Cispus workshop facilitators and rapporteurs: Dustin Bengtson, Peg Boulay, Maya Fuller, Norman Hesseldahl, Diane McClay, Tom Poplawski, and Mark Wilkening.

Section II. Overarching Themes, Potential Consequences, and Overall Research Strategies

Overarching Themes

Important overarching themes emerged from the consultation. First, anticipatory rather than reactive management is needed to address marine mammal issues. Past funding decisions and allocation of human resources have been driven by the development of management crises, including extensive litigation. Witness the recent, still-unexplained collapse of the western population of Steller sea lions, the inability of endangered North Atlantic right whales to recover because of ship strikes and entanglement in fishing gear, and the controversy over multiple strandings of beaked whales in close proximity to naval operations in various regions of the world. These and other situations exemplify the inadequacy and inefficiency of crisis management. Unforeseen problems are unavoidable, but problems that can be anticipated should be addressed in advance. One particularly clear example is the effect of changing power production practices in Florida, where the warm-water effluent from thermal power plants currently provides winter refugia for manatees. As these facilities are gradually decommissioned and replaced by new technologies, an alternative arrangement for manatees will obviously and predictably be needed.

A second theme was the need to integrate scientific disciplines into a more holistic multidisciplinary approach that will provide a better understanding of marine mammals within their ecosystems. The effects of disease, contaminants, noise, harmful algal blooms, and long-term environmental change were considered to be interrelated and quite possibly synergistic, meaning that none of these stressors could be properly diagnosed, studied, and managed in isolation from the others. The health of individual animals and populations is intimately linked to a suite of closely intertwined factors. Interdisciplinary approaches are essential but will require some restructuring of existing research institutions with increased and reallocated funding.

A third theme is related to the concept of health. Although the term "health" is traditionally used to characterize individuals, Congress extended this concept to populations and ecosystems in the Marine Mammal Protection Act. Under the Act, the health or status of a population is determined solely by abundance. In recent years, managers and scientists have observed a need for a broader vision. In addition to efforts aimed at reducing mortality (e.g., from hunting, bycatch, ship strikes) and programs to monitor animal numbers and distribution, animal health should be a major focus of research and management. The health of individual animals within populations is linked to the status of those populations, as health ultimately affects reproduction and survival. Furthermore, declines in marine mammal populations caused by disease, contaminants, harmful algal blooms, noise, or other environmental stressors can be warning signs of a decline in ecosystem or ocean health and also could have far-reaching implications for human health and well-being. This theme arose repeatedly during the consultation and is reflected in many of the recommendations below.

Fourth, regarding the potential effects of human activities, the lack of conclusive evidence of harm does not necessarily mean that no harm has occurred. In the absence of adequate information, assessment of potential human effects can result in two types of error. One type occurs when it is mistakenly concluded that an action has a significant environmental effect. This is referred to as a type I error and may lead to over-regulation of human activities by providing more protection than is required. The second type of error (type II) occurs when it is mistakenly concluded that an action does not have a significant environmental effect. This kind of error may lead to inadequate protection. When faced with uncertainty about the significance of effects it is crucial to determine where the burden of proof lies (i.e., whether type I error or type II error should get the most attention). At least three main questions arise: (1) Who should pay the costs of scientific research to investigate potential effects? (2) What standard of proof should be used to judge whether an action will have significant effects? and (3) What should be the default conclusion until sufficient evidence has been gathered to satisfy the standard of proof? It was generally agreed that:

- Conservation demands that higher priority be assigned to avoiding type II error than to avoiding type I error.
- The burden of evaluating the nature and extent of potential harm that will result from a proposed use or activity should reside with those who stand to benefit from that use or activity. Government

agencies and non-governmental organizations simply do not have the resources to assume that burden.

Finally, participants repeatedly emphasized the need to acknowledge scientific uncertainty and to quantify and incorporate such uncertainty into decision-making. This requires not only the development and application of new scientific methods but also the inculcation of new perspectives into the socio-political culture. Management needs to be precautionary, that is, take account of scientific uncertainty and provide a reasonable level of assurance that significant adverse effects will not occur.

Potential Consequences of Not Pursuing the Recommended Research Agenda

Participants were asked to describe the expected consequences of not pursuing a more integrated, holistic, and anticipatory marine mammal research agenda. These potential consequences are summarized as follows:

- The goals of the Marine Mammal Protection Act—maintaining healthy marine ecosystems with marine mammals in their optimum sustainable population range —are less likely to be met.
- The relative roles of anthropogenic and natural factors in regulating marine mammal populations will continue to be difficult to distinguish, and important human-related effects may go undetected.
- The roles of various stressors will be poorly understood, their future significance will be difficult to anticipate (particularly for endangered species), and suitable conservation measures to avoid or mitigate their effects will be difficult to develop.
- Management and scientific responses to controversial events will continue to be reactive rather than proactive, opportunities for early intervention will be missed, and the ultimate cost of addressing important but neglected problems will be increased.
- Die-offs, population declines, and other problems will go unexplained, and key questions will go unanswered (e.g., why are they dying or why are they not reproducing at the expected rate?).
- Similarly, dispersal of marine mammals into "new" areas, or local increases in their numbers, will go unexplained. Thus, it will not be possible to determine whether such phenomena represent recovery and return to historical conditions or instead reflect a re-

sponse to long-term changes caused in whole or in part by human actions.

- The toxicity of new chemical compounds, the impacts of new noise sources, the occurrence of and risks associated with harmful algal blooms, and the implications of human-influenced disease transmission will remain unknown or uncertain. As a result, harmful chemicals will continue to be released into the environment, ocean areas will become noisier and less habitable for marine mammals and other organisms, and their health and the health of marine ecosystems will continue to deteriorate.
- The role of disease as a determinant of marine mammal health and population status will remain unclear. Inadequate diagnostic efforts and evaluation of proximate and ultimate causes not only put individuals and populations at risk but also may lead to waste of financial and human resources.
- The continued occurrence of disease, particularly in coastal marine mammal populations, may have public health consequences and disrupt economic activities, leading, in turn, to broader and more costly social impacts.
- Inadequate attention to significant but more subtle threats of disease, noise, and contaminants may reduce the benefits of measures designed to protect marine mammals from more obvious, well-characterized threats such as hunting, bycatch in fisheries, and ship strikes.
- Some populations or species may decline significantly or even become extirpated before causative factors are identified, characterized, and addressed. Examples of species at particular risk include the deep-water, poorly studied beaked whales in the case of high-intensity human-induced sound; manatees and southern sea otters in the cases of harmful algal blooms and disease; and ice-associated seals in polar regions experiencing loss of habitat due to global climate change.
- Human communities may lose economic opportunities (e.g., subsistence hunting and mammal-oriented tourism) as marine mammal populations decline or shift their distribution.
- In the absence of reliable information about specific areas and species, Alaska Natives who depend on marine mammals for subsistence may either underestimate risks from contaminants and consume contaminated marine mammals or overestimate risks from contaminants and suffer cultural and health impacts from an unnecessary change in diet.

- Managers lacking suitable scientific information may be more likely to err, both by failing to provide suitable protection for marine mammals and by imposing unnecessary and costly regulations on business, shipping, recreation, and other human activities.
- Without a better understanding of long-term environmental variability, it will be difficult to distinguish human-related problems from those that arise simply from poorly understood natural fluctuations.
- Without clear and specific legislative standards and decision rules, we increase the risks of perpetuating unnecessary debate and conflict, making inconsistent management decisions, failing to adapt management based on past experience, failing to meet stated management objectives, wasting resources, and extirpating species and degrading ecosystems.

Overall Research Strategies

The workshop identified a number of overall research strategies, which are summarized here. Closely linked items appear in sequence, but no attempt has been made to rank the strategies in terms of their importance or cost. These strategies, like many of the threats they are intended to address, tend to be interactive if not directly related.

Units to Conserve

An understanding of population structure is essential for assessing and conserving populations and the ecosystems in which they occur. Advances in the field of genetics are rapidly increasing our ability to identify populations, which will both change scientific understanding of how they function and require suitable adjustments in management strategies. Without such adjustments or adaptation, management strategies are less likely to achieve their conservation goals, as established in legislation. The unit of conservation is relevant not only in the context of domestic legislation, but also when U.S. scientists and managers are engaged in the work of international bodies such as the International Whaling Commission, the Inter-American Tropical Tuna Commission, and Convention on International Trade in Endangered Species (CITES). Therefore,

Investigation of marine mammal population structure must be enhanced if scientists are to identify the appropriate units of conservation based on biological information.

Efforts to collect, archive, analyze, and exchange the genetic samples needed to delineate conservation units must be supported at a national scale.

Population Effects

Another pervasive challenge in conservation science is to quantify the effects of various threats at the population level. Although it can be extremely difficult to establish cause-and-effect linkages at the individual level, it may be more difficult to determine the extent to which mortality, morbidity, or compromised health associated with a particular agent (disease, chemical pollutant, etc.) or a suite of stressors is affecting a population. Therefore,

Methods are needed for extrapolation from individuals to populations when assessing the effects of various mortality and stress factors.

Health Assessment and Die-off Response

Declining trends in animal populations can result from increased mortality (e.g., bycatch, ship strikes, acute diseases, poisoning from toxic algal blooms), decreased reproduction and recruitment into the breeding population (e.g., due to reduced fecundity from exposure to contaminants, inadequate nutrition to sustain pregnancy and lactation), or some combination of both. Factors such as disease, contaminants, harmful algal blooms, artificial underwater sound, and environmental changes of various kinds must be considered in an integrated manner rather than only as discrete stressors on marine mammals. Therefore,

A more coherent and comprehensive infrastructure is needed for investigating marine mammal health in a systematic, holistic manner. It should include a multidisciplinary approach; improved diagnostic tools for assessing health and linking health indicators to stress factors; better distinction between natural and human-caused mortality; better estimation of actual mortality by extrapolation from observed mortality; and an efficient, coordinated response mechanism for mass mortality events.

Abundance Estimation

Abundance is a key indicator of population status. Abundance changes as a result of four factors only: survival, reproduction, immigration, and emigration. Abundance of some stocks and species of marine mammals in U.S. waters has yet to be estimated. Estimates for a number of other stocks or species are too imprecise to support conclusive inferences about population trends from one survey to the next. These estimates also are often too imprecise to determine the effects of various factors on marine mammal populations and to determine whether conservation measures are working. Therefore,

Development of methods for estimating abundance accurately and precisely should continue.

Existing levels of support for abundance surveys of all marine mammal populations in U.S. waters must be increased.

Population Monitoring

Major progress has been made over the past 30 years in achieving understanding of marine mammal populations in U.S. waters. We know a great deal more now than was known when the Marine Mammal Protection Act came into law. Many positive (and some negative) lessons have been learned. One important lesson is that no wild population, however abundant and widespread, should be ignored and assumed to be secure. The precipitous but still unexplained declines of Steller sea lions, harbor seals, and sea otters in some regions of Alaska over the past 10–20 years were unexpected. All populations should be monitored closely enough to ensure that trends are known and changes in population status are detected in a timely manner. Therefore,

Increased monitoring is essential to ensure that all marine mammal populations are adequately assessed at regular intervals, regardless of their current conservation status. Such monitoring is essential to detect changes in population status and to examine the efficacy of management measures.

Risk Assessment and Decision Analysis

Risk assessment has emerged as a key decision-making tool for conservation management. It requires an ability to characterize threats and the risks they pose to a population. The value of risk assessment is determined largely by the availability of suitable and sufficient data on the marine mammals involved, the levels of exposure to specific threats, and the known or probable consequences of exposure.

Decision analysis is the science of developing formal protocols for decision-making. Risks and costs should be modeled in advance, and acceptable outcomes defined so that decisions, when needed, can be made on a rational basis. Therefore,

Further development of risk assessment and decision analysis methods is essential and should be encouraged and supported.

Research and monitoring should be undertaken to assess various threats and provide the information needed for formal risk assessment.

Modeling (Validation and Prediction)

Models, whether conceptual or mathematical, provide an important and often the only means for integrating existing information on marine mammals and marine ecosystems, identifying gaps in our understanding of marine ecology, testing hypotheses about past events (e.g., hindcasting), and projecting the potential future effects of possible management strategies (e.g., forecasting). In short, modeling is essential for proactive management based on the best available data. However, the value of models is determined by their accuracy and reliability, which is usually determined by processes collectively referred to as validation. Validation is essential to assess the basis for confidence in modeling results. The reliability and utility of ecosystem models, which will be essential for ecosystem-based science and management, will be highly questionable if those models have not been validated. Validation will require comprehensive, multidisciplinary research programs carried out over long periods of time to provide the information needed to run the models and validate their results. Therefore,

Management should incorporate long-term monitoring to gauge policy effectiveness and detect population change and to validate the results of predictive modeling.

Reliable predictive modeling should be incorporated into management to provide managers with credible, comprehensible, and forward-looking advice.

Long-term Studies and Ocean Monitoring

Much of the information needed to (1) assess marine mammal population status and trends, (2) understand their biology, behavior, and ecology, and (3) determine the effects of various natural and anthropogenic threats to them can only be gained through long-term studies. Many of the most significant insights about marine mammals have come from long-term studies such as photo-identification studies of humpback, right, and killer whales and the capture-sample-release studies of bottlenose dolphins in Florida. Each additional year of data from these long-term programs provides information of greater scientific and conservation value. Although some long-term programs have been initiated to investigate certain aspects of marine mammal populations and their oceanic environment, existing levels of support are inadequate for such studies, and much of the information essential for management and conservation is not being collected. Therefore,

Existing long-term research programs on marine mammals should be maintained.

Additional long-term research programs should be developed and supported. Programs are especially needed to investigate the ecology of marine mammal populations and the manner in which they are affected by various natural and human-related factors.

Marine mammal investigations should be integrated into existing ocean monitoring programs.

Marine Protected Areas

Precautionary management requires mitigation and protection strategies that compensate for the extensive uncertainty associated with virtually all aspects of marine mammal science. The conservation value of protected areas is well established and widely acknowledged. The establishment of protected areas that exclude certain types of human activity can be economically costly in the short term, but such areas also provide substantial immediate and long-term economic benefits, ranging from fishery enhancement to recreational and educational opportunities for the public. Moreover, protected areas represent control sites for experimentation and comparative analyses. Therefore,

Existing marine protected areas (including parks, sanctuaries, and reserves) should be given adequate support to achieve their objectives.

Additional marine protected areas should be designated and developed to conserve marine mammals and protect their habitat.

Section III. Topical Summaries and Specific Recommendations

Each of the main topics addressed in the consultation is summarized here based upon the relevant background paper and the discussions at the Consultation. None of these threats or issues exists in isolation. Many of the threats are interrelated, and their effects can be cumulative, synergistic, additive, or perhaps even antagonistic in some instances. The first four topics, in particular, were judged to be closely linked and overlapping.

Direct Fishery Interactions

The Issue

Incidental mortality and serious injury of marine mammals in fisheries (i.e., bycatch) is a long-standing conservation problem. Some species, most notably the vaquita in the Gulf of California (Mexico), are at risk of extinction primarily because of this threat. For others, such as the Mediterranean monk seal and North Atlantic right whale, it is one of several serious risk factors that could tip the balance against their persistence.

Depredation is another form of direct fishery interaction in which marine mammals remove or damage fish captured in the gear, thus reducing the value of the catch and impairing fishing operations. In Alaska, sperm whales and killer whales strip sablefish off longline gear. In California, harbor seals damage net-caught salmon, causing significant economic loss. The problem of depredation has long been recognized, but little progress has been made toward its amelioration.

In contrast, the management regime imposed by the Marine Mammal Protection Act has been generally effective in reducing incidental mortality and serious injury of marine mammals, although improvements are still needed (e.g., better information on stock structure and more reliable mortality estimates). In many gillnet fisheries, entanglement and mortality of dolphins and porpoises have been reduced to sustainable levels by measures such as time/area closures and mandatory use of acoustic deterrents (“pingers”). Reported mortality of dolphins in the tuna purse seine fishery has been reduced considerably as a result of mitigation measures developed through collaboration between government and industry. In much of the rest of the world, however, and particularly in developing nations, progress in addressing marine mammal bycatch has been slow or non-existent. Bycatch reduction, especially in gillnet fisheries, is urgently needed to ensure the persistence of many marine mammal populations.

Bycatch—Needed Research

Some fundamental questions need to be addressed to effectively reduce bycatch:

- How do marine mammals get caught in fishing gear?
- Once caught, why are they unable to extricate themselves?
- Are there delayed effects on entangled animals that subsequently escape or are released?
- How can we estimate the magnitude of marine mammal bycatch in fisheries without on-board observer programs?
- What new gear types or fishing techniques can reduce bycatch while still allowing economically feasible fishing?

An improved understanding of the magnitude and impact of bycatch is needed for fisheries in many parts of the world, including some unmonitored fisheries in U.S. waters. Incidental mortality of marine mammals in recreational fisheries and "ghost" nets (i.e., discarded and derelict fishing gear) has not yet been adequately addressed although progress is being made in some areas (e.g., the large-scale program to remove snagged and beached gear threatening monk seals in the northwestern Hawaiian Islands). Bycatches in globally widespread illegal, unreported, and unregulated fisheries also have not been addressed but could easily deplete or extirpate vulnerable marine mammal populations.

Well-designed observer programs are needed to monitor bycatch, but these are difficult to implement and manage. Analysis of observer data is needed, not only to estimate bycatch but also to provide insights about fishing operations and animal behavior that could facilitate bycatch mitigation. Marine mammal behavior around fishing gear and the circumstances that lead to entanglement are poorly understood and need additional study. Opportunities for such observations are relatively rare, and it is therefore important to take advantage of those that become available, whether in the wild or with captive animals under controlled conditions. Shipboard cameras and other technology may be essential to understand marine mammal behavior and circumstances leading to entanglement.

Methods for reducing bycatch also must be investigated. The Medina panel and backdown procedure were developed by fishermen and have been instrumental in reducing dolphin bycatch in the eastern tropical Pacific tuna fishery. The turtle excluder device was crucial in reducing turtle mortality in shrimp fishing operations. Pingers have been shown effective in reducing cetacean bycatches in some gillnet fisheries. The involvement of fishermen was indispensable in developing those bycatch reduction tools and will be vital in efforts to devise and field-test new mitigation methods and procedures, whether for gillnetting, trawling, or other types of fishing that result in bycatch.

Bycatch—Needed Management

In the United States, significant accomplishments have been made in stock assessment, acquisition of observer data, establishment of clear management objectives, development of scientific criteria, and involvement of stakeholders. Nevertheless, improvement and expansion are needed in all of those areas. Bycatch reduction inevitably requires changes in human activity patterns and choices, and the political will to achieve such reduction is essential for successful implementation of mitigation measures. Around the world, education is needed to increase awareness and foster such will wherever it is lacking. In addition, the appropriate expertise and bycatch reduction technology must be made available wherever needed.

Science and policy must be distinguished when addressing fishery conflicts. The development of assessment, analytical, and ameliorative tools is a scientific endeavor, albeit one that demands the engagement not only of scientists but also of fishermen and technical specialists with practical knowledge gained from experience. Policy formulation is enhanced by a solid scientific foundation as well as sensitivity to the interests of multiple stakeholders, including both fishermen and people whose primary concern is conservation and animal welfare. A combination of rigorous science and effective policy is needed to further reduce bycatch. With regard to U.S. fisheries, additional efforts are needed to —

- Maintain and assess the efficacy of take reduction teams to address marine mammal bycatch problems.
- Define the "zero mortality rate goal" of the Marine Mammal Protection Act.
- Reconcile the conflicting objectives of fishery development and biodiversity conservation to provide a clear and unequivocal national policy regarding the relative weight given to short-term

economic benefits from fishing versus longer-term maintenance of ecosystem structure and function.

- Analyze fishery observer reports to identify bycatch mitigation measures, such as changes in fishing operations.
- Offset the competitive disadvantage to U.S. fishermen from bycatch-related restrictions applied to them but not to foreign fishermen. For example, Icelandic cod fisheries have a substantial bycatch of harbor porpoises and other marine mammals but are not subject to any bycatch mitigation regulations (e.g., time/area closures, mandatory pinger use).
- Develop innovative funding programs to assess and mitigate marine mammal conflicts with fisheries, possibly including levies against the industry and consumers to pay for observer programs, population monitoring, and the design and testing of new mitigation tools.
- Encourage high-value, low-volume fisheries as a strategy for reducing fishing effort and thus reducing marine mammal bycatch.

Efforts at bycatch reduction in non-U.S. fisheries should —

- Extend U.S. approaches for reducing marine mammal bycatch to fisheries in other countries when such extension is appropriate and feasible. Socioeconomic and political conditions may preclude simple transference, and creative adaptations or altogether different approaches may be required.
- Engage the Committee on Fisheries of the United Nations Food and Agriculture Organization, other appropriate regional fishery management organizations, and bilateral agreements to promote bycatch reduction initiatives.
- Provide scientific support for programs seeking to develop responsible fishing practices (e.g., those involving no or minimal bycatch of marine mammals) through product labeling and other means of influencing consumer choice.
- Create economic incentives to encourage low technology fishing methods, inexpensive modifications to fishing gear, and other changes in fishing practices that will reduce marine mammal bycatch. Successful attempts to reduce direct effects (e.g., in Madeira, where incidental mortality of Mediterranean monk seals was brought under control) should be catalogued and publicized.
- Describe and emphasize the ancillary benefits of steps taken to reduce marine mammal bycatches, such as reduced bycatches of other species.

- Support scientist exchange programs as mechanisms for transferring skills in population assessment, bycatch estimation, and bycatch mitigation.

Depredation—Research and Management

Although depredation by marine mammals may be unavoidable at some level, it should be possible to reduce its frequency and mitigate its effects. Depredation problems may be best addressed using the take reduction team approach.

Scientific information is necessary to ensure that perceptions about depredation are accurate and that lethal or otherwise harmful measures are not used against marine mammals as scapegoats. The behavioral and environmental context of depredation requires additional study. For example, information is needed on the prevalence of depredation behavior within a marine mammal population and on the transmission of such behavior among individuals and from one group to another. Terrestrial analogues may provide useful models for studying depredation by marine mammals.

The consultation agreed upon the following recommendations in relation to depredation:

- Establish and require data collection programs to determine the frequency of depredation by marine mammals (and other predators), the associated economic costs, and any correspondence between the frequency or severity of depredation and the characteristics of different fishing vessels.
- Ensure that remedial measures are properly field-tested to demonstrate their effectiveness prior to widespread adoption.

Interactions with Other Topics

Direct fishery interactions may kill animals immediately but also may cause sub-lethal injury or stress. Individuals so compromised may be susceptible to other adverse factors, including disease. Acoustic trauma (e.g., temporary or permanent shifts in hearing thresholds) may reduce the efficiency of an animal's echolocation system, making it more vulnerable to bycatch. Also, poor condition as a result of illness or exposure to biotoxins or chemical contaminants could make an animal more prone to incidental capture in fishing gear. The problems of direct and indirect fishery interactions, as distinguished in the consultation and in this and the following sections of the report, are interactive at many levels.

Indirect Fishery Interactions

The Issue

Competitive interactions between marine mammals and fisheries have been the subject of much debate. Some Canadian fishermen and politicians have blamed the large and increasing population of harp seals in the western North Atlantic for the failure of groundfish stocks to recover after their fishery-induced collapse in the early 1990s. Norway has partially justified its ongoing hunt for minke whales as a cull needed to protect fishery resources, and both Japan and Iceland have used similar arguments to justify their "scientific" whaling programs. From another perspective, fisheries may be reducing the environmental carrying capacity for marine mammal populations. Large-scale reductions of pollock and other groundfish by commercial fishing may have contributed to the rapid decline of Steller sea lions in parts of Alaska.

The presumption of competition is not surprising because most marine mammals eat fish or invertebrates, many of which are also targeted by fisheries. Even when the diets of marine mammals and targeted species in fisheries do not overlap directly, predator-prey relationships can result in complicated interactions. "Beneficial predation" refers to situations where one predator species consumes another, thereby reducing predation on the prey of the second predator. For example, California sea lions consume lampreys, thereby reducing predation of lampreys on salmonids. The concept of beneficial predation calls into question the simplistic assumption that a reduction of high-order predators by culling will directly improve fishery yields. Such assumptions are often misleading because of the complex nature of ecological interactions in marine ecosystems.

Ecosystem management has been invoked as an imperative in international agreements and domestic policy but has proven extraordinarily difficult to implement due to ecosystem complexity. Multi-species mathematical models are proving to be useful, albeit controversial, tools for investigating that complexity.

Needed Research

The utility and reliability of models are a matter of considerable disagreement. Some scientists believe strongly in their utility, and others reject them as misleading and unreliable. They should be used cautiously as explanatory and predictive tools. Their predictive value is often limited, however, by insufficient empirical data on species and populations, the dynamics of feeding behavior, and the undocumented and unforeseen interactions among different types of organisms. The biology, ecology, behavior, and physiology of the animals being modeled are generally poorly known. Models can nevertheless help to identify information gaps, and they can be used, cautiously, to guide research design and data collection. They can also be used to identify and select analytical and management options. Temporally and spatially explicit models can aid in the design of time and area closures

Models are rarely able to provide reliable quantitative advice on, for example, the expected response of fishery yields to changes in marine mammal abundance, or vice versa. They are more likely to provide reliable qualitative information, but even then, considerable caution is needed because of the complexity of the ecological interactions involved. The uncertainty associated with any predictions must be clearly and exhaustively documented. Further, the robustness of model results must be examined by thorough sensitivity analyses. Finally, modelers and the users of modeling results must be aware of the potential for ecological bias when all of the ecologically important species are not included in the model, often due to a lack of sufficient information on those species.

Participants recommended that a variety of models should be applied to one or more biological systems for which sufficient data are available, with the goal of determining whether the conclusions they produce are qualitatively similar. This kind of exercise provides an opportunity for comparing model assumptions and results and may provide weight-of-evidence support in the assessment of risks related to a particular management issue or measure. It relies heavily upon the availability of appropriate data.

Model validation should consist of a series of steps, as follows:

- Test the model using an ecosystem or an indirect-effects problem for which adequate data are available.
- Compare model results to results of other models addressing the same issue(s) and using the same data.
- Ensure that the model is sufficiently robust and reliable to address the question at hand in the context of pertinent statutes and regulations (e.g., the Marine Mammal Protection Act or the Endangered Species Act).
- Critically examine the implications of model assumptions and defaults.
- Subject the results to rigorous peer review.

- Conduct further validation using different systems (or problems) and more data. A feedback, or adaptive, approach is desirable, such that future data are used to reduce uncertainty in an incremental or stepwise process.

A panel of independent experts (such as those convened by the Center for Independent Experts to address fisheries-related issues) may be needed to provide a consensus view of how modeling results should be interpreted and when validation is sufficient. Such a peer-review group could also provide guidance on further applications of any given model. In the long term, models that perform well in such trials may be useful for predicting the likelihood that particular management actions will be successful in changing marine mammal numbers or fishery yields through indirect effects.

The validity and value of modeling will be enhanced by the following:

- Investigations of the functional responses of predators to changes in prey availability.
- Better understanding of species biology, physiology, and behavior.
- Greater availability and reliability of the data needed for modeling exercises (e.g., through more and better-designed monitoring surveys, extension of data collection to include mid-trophic-level organisms). The more species and other factors for which empirical data are available, the more credible and useful the modeled results will be.
- Development of appropriate methods to verify model predictions.
- Better tools for assessing the nutritional and health status of individual marine mammals.
- Incorporation of pertinent environmental parameters or influences (e.g., climate change, regime shifts).

Reasons for caution when using multi-species models include the following:

- Diets and foraging habits of marine mammals are often difficult to characterize in a quantitative way. Some species are highly specialized and spend large amounts of time searching for patches of preferred prey, while others appear to be generalists.
- Diets of individual animals may vary as a function of age or life stage, sex, geographical distribution, and even changing environmental conditions (e.g., gray whales).

- Variability in diet at the level of the individual (e.g., sea otters) can represent a serious challenge to modeling that depends upon "average" characteristics for the population.
- Diet characterizations can be strongly influenced by the methods used, leading to false assumptions about differences or similarities.
- Data on fishery catches are often unreliable and incomplete (e.g., they may fail to account for bycatch, unreported catch, and discards).
- Some systems, or some problems, may simply be too complex to model (e.g., it may never be possible to disentangle the roles of climatic and human factors in the massive declines of some marine mammal populations in Alaska).
- A distinction must be maintained between modeling to inform research and modeling to make management decisions.
- Comparisons among models must recognize that model "error" often arises from the models themselves and does not necessarily reflect erroneous assumptions or inputs.

The following research topics were flagged for special attention:

- The United Nations Food and Agriculture Organization has predicted that fisheries for squid are likely to expand dramatically over the next decade. Many marine mammal species, including some whose biology is poorly known, appear to be dependent upon squid. Therefore, modeling should be conducted in advance as a way of anticipating the ecosystem-level effects of these fisheries. New fisheries for other "underutilized" species can also be expected, and the same desideratum would apply to them.
- Large-scale, carefully designed ecosystem experiments, with adequate controls and adequate monitoring, would greatly enhance the power of modeling. The literature from terrestrial ecology demonstrates the value of experimental perturbation and long-term monitoring as an approach to model development and validation. However, experimentation is generally more difficult with marine than with terrestrial ecosystems. Marine systems tend to be more interconnected and less easy to cordon off into separate areas for treatment or to serve as controls. Moreover, replication, the main means used to reduce confounding, is generally impractical for marine mammals. One proviso of all large-scale experiments is that a long-term commitment to monitoring is essential (including

long-term funding), as changes seen in the first few years after perturbation may not be representative of the ultimate effects.

Interactions with Other Topics

Ecosystem models must be informed to the greatest extent possible by empirical knowledge concerning animal health and life history, which are affected by disease, contaminants, and other stressors. The general need for improved and expanded monitoring applies to several topics, including the indirect effects of fisheries, long-term environmental change, and units to conserve. Changes predicted by models can only be validated against indices that are tracked by monitoring programs. Modeling is also closely tied to management insofar as models are used for decision-making.

Disease

The Issue

Diseases occur naturally in animal populations, but human activities can introduce them, affect their transmission, and alter the animals' susceptibility to them. Disease can affect survival and reproduction and is a particular concern for small populations. Evidence suggests that disease has been increasing in recent decades for some marine mammal populations. Mass mortality events, some involving thousands of animals, have been observed and can pose grave threats to the affected populations, particularly those that are already small or endangered. Recent examples of major disease events include outbreaks of phocine distemper virus in European harbor seals in 1988 and again in 2002 and dolphin morbillivirus in bottlenose dolphins along the Atlantic coast of the United States in 1987–1988. In another example, California sea otters have been shown to be susceptible to a form of meningitis transmitted via the feces of domestic and feral cats. The prevalence and consequences of disease may be exacerbated by interactions with human-related factors such as contaminants, habitat loss, and reduced amount or quality of prey. Indeed, disease may have significant ecological, social, and economic impacts and the incidence of disease may serve as an indication of deteriorating environmental conditions.

Needed Research

Investigation of disease is a legitimate aspect of conservation biology and must be recognized as such. Research is needed to understand the factors that cause disease, the role of anthropogenic factors in disease transmission and animal susceptibility, and the effects of disease on the status of marine mammal populations. Such research is essential for remedial measures, including prevention, response, and management to facilitate population recovery and prevent future population decline. For the most part, disease studies of marine mammals have been opportunistic and reactive rather than systematic and anticipatory. Although scientists and managers must respond quickly when disease is suspected, more systematic investigations of disease are also needed. Diagnostics, population surveys, interpretation of effects, and description of environmental conditions are all needed to determine the demographic and ecological significance of disease outbreaks.

Research and management needs can be sorted into four categories – disease identification (diagnostics), determination of causes (etiology), assessment of impacts, and mitigation of effects.

Disease identification should include the following:

- Determination of research priorities based upon vulnerability (e.g., endangered species).
- Development of indicators of health, condition, and disease.
- Development of biomarkers or indicators and identification of transmission/vectors.
- Rigorous, systematic sample collection from both healthy and diseased animals.
- Diagnostic laboratory facilities (specific to marine mammals) using the best available diagnostic measures and development of new measures where needed.
- National and international coordination of sample collection, analysis, and archiving.

Determination of causes should include the following:

- Identification of single and cumulative factors at both individual and population levels.
- Distinction between primary causes and predisposing factors, and the nature of their relationships.
- Differentiation of human-related from natural factors.
- Determination of disease vectors and methods of transmission.

Assessment of impacts should include the following:

- Determination of populations affected.
- Assessment of baseline conditions (population and environment) and implementation of suitable monitoring.

- Assessment of the role of disease in morbidity, mortality, reproduction, etc.
- Extrapolation from observed effects (carcass count) to actual effects.
- Impact assessment at individual, population, ecosystem, and socioeconomic levels.
- Projections of the potential role of future disease.

Mitigation of effects should include the following:

- Prevention, particularly when the occurrence and effects of disease are influenced directly or indirectly by human activities or when highly vulnerable populations may be affected.
- Event response, for the purposes of providing humanitarian care and conducting scientific investigations of the disease process and its consequences.
- Management of the aftermath of a disease outbreak/die-off, including development and implementation of measures to facilitate population recovery and prevent future episodes.
- Distinction between natural disease processes and those influenced, triggered, or facilitated by human actions.

An inventory of marine mammal diseases, ranked by importance to marine mammal populations, is needed to prioritize research efforts. Diseases directly or indirectly related to human activities, and therefore perhaps more preventable, should be identified, as well as diseases that pose a risk to humans, domestic livestock, and wild populations of other species.

To investigate disease, it is necessary to consider effects at both the individual and the population level. For the latter, it is necessary to know some basic characteristics about the population, e.g., its geographical range and patterns of movement, abundance, age and sex structure, and vital rates. Such data are available for a few key species, but this base of information needs to be expanded and updated (see other sections of this report).

The institutional infrastructure to support investigations of disease in marine mammals is currently inadequate, and therefore enhancement of that infrastructure is a priority. Better tools and facilities are needed for diagnosing disease and archiving samples. New diagnostic tools are needed, as are better statistical capabilities for exploring disease etiology and risk. Investigation of diseases is complicated by the fact that, in nature, animals are simultaneously exposed to multiple stressors, including multiple diseases. Linking an individual's health or condition to a particular disease agent is difficult and becomes even more complex when the population, rather than individual animals, becomes the focus of concern. Mathematical modeling can provide an important tool for identifying the most important areas of research and for exploring various scenarios of interaction among stressors. It can also help elucidate the full effects of a disease outbreak and predict future patterns of disease incidence and impact.

Multidisciplinary investigations of disease depend upon the availability of resources in the form of laboratories, equipment, personnel, and funding. Current resources should be inventoried and expected future needs described to determine where additional resources are essential. In some cases, resources may be found in fields not yet closely associated with marine mammal science, and those resources should be tapped to provide essential diagnostic and research capability. Long-term funding is essential due to the inherent difficulty of disease investigations and the potential for altered expressions of disease in ever-changing environments.

One approach would be to have a network of separate laboratories, each with a different mix of expertise, linked by a common mandate and funding base. A central clearinghouse would be necessary to make this work efficiently. Such an approach could be pursued with existing facilities, but it would require institutional commitments, coordination, and continuity of funding at adequate levels (Appendix E).

Interactions with Other Topics

Increasing urbanization of coastal zones is associated with the spread of pets and other domestic animals, sewage disposal, and inputs of contaminated runoff. These factors, together with contaminants and harmful algal blooms, may increase susceptibility to or occurrence of disease. Disease must be investigated and evaluated in conjunction with overall animal health and in relation to other stressors that are known or likely to be interactive. Integrated, multidisciplinary investigations of disease are, therefore, essential.

Contaminants

The Issue

Contaminants have proliferated over the years and found their way into the marine environment where many of them are almost ubiquitous. The concept of "pristine" no longer exists in an absolute sense, and we can now only compare the relative degrees of contamination of different habitat areas. While the worldwide, aggregate trend of environmental contamination is probably increasing, particular toxicants in specific regions can be either increasing or decreasing. Contaminants may originate from local sources or be transported from distant sources via the atmosphere or ocean currents. By 1999 some 20 million chemicals had been registered, yet only a relatively small proportion of that number has been included in standard assays of marine mammal tissues. Moreover, a large and increasing number of chemicals (2,000 to 3,000 new chemicals are registered every year) are being released into the environment after only limited testing for their effects on wildlife.

Marine mammal tissues are known to accumulate contaminants that cause health problems in laboratory animals (e.g., mice, rats, mink). In fact, marine mammals have some of the highest levels of known contaminants and are at risk because they are at the top of the food chain and are long-lived. Publicity concerning the very high levels of PCBs and DDTs in the blubber of beluga whales from the St. Lawrence River (Canada) and killer whales off Washington and British Columbia has caused alarm. Studies of polar bears in Svalbard (Norway) suggest that exposure to high levels of organochlorines via the food chain (these bears prey mainly upon ringed seals) can lead to endocrine disruption and reproductive dysfunction. However, experimental data on the effects of contaminants on most marine mammal species are conspicuously lacking. Although much effort has been devoted to measuring levels of contaminants in marine mammals, little effort has been directed at identifying cause-and-effect processes. Effects have been inferred based upon limited experimental research with a few species, especially the harbor seal. Contaminants can affect a marine mammal directly or indirectly by damaging its food sources. The effects of chronic, sub-lethal exposure to contaminants are poorly understood. The scarcity of direct evidence for cause and effect generally extends to humans who are exposed to contaminants through multiple pathways, including the consumption of marine mammals as food.

Assessing potential impacts of currently used and new chemicals on marine mammals presents a number of scientific, logistical, and ethical challenges to scientists and government agencies charged with approving the use of chemicals and with managing marine mammals. The Environmental Protection Agency and companies assess the effects of chemicals on some laboratory animals but not on marine mammals. Nonetheless, some level of testing appears to be necessary if scientists are to understand the effects of contaminants thought to pose significant potential risks.

Needed Research

The state of knowledge regarding marine mammals and persistent ocean contaminants has changed little since the Marine Mammal Commission's 1998 workshop on this subject in Keystone, Colorado. The report of that workshop (O'Shea et al. 1999) continues to provide a valuable template for needed research. In addition, two recently published reviews summarize documented or proposed effects of contaminants on marine mammals (O'Hara and O'Shea 2001: see pp. 472–476) and associations between high tissue contaminant levels and various disorders in marine mammals (Reijnders in Vos et al. 2003: see pp. 56 and 821).

Participants in the workshop identified a number of important general and specific questions regarding research on the effects of contaminants:

- What is the value of using marine mammals as indicator species? Are they useful sentinels of the "health of the oceans"?
- How can we extrapolate from the results of effect studies on one species (model or surrogate) to predict effects on other species, particularly marine mammals?
- How can we extrapolate data on contaminant burdens and their effects on individuals to the implications for entire populations?
- How do contaminants and other stressors interact, and are their combined effects additive, synergistic, or antagonistic?
- What new or emerging contaminants should be monitored in marine mammals (this could be based upon likelihood of exposure and effect)?
- Do marine mammals have unique physiological adaptations that alter their sensitivity to and tolerance of certain classes of contaminants?
- What are appropriate model or surrogate species for marine mammal contaminant research (keeping in mind the difficulties of using marine mammals directly)?
- Can standard epidemiology tools or models be applied reliably to marine mammals?

Based on those questions and recommendations from the authors of the background paper, consultation participants made the following research recommendations:

- Conduct experimental research on sublethal effects of organochlorine compounds and other contaminants on selected marine mammal species (e.g., captive California sea lions). Examine dose-response relationships, including significant responses to low contaminant concentrations, testing for physiological responses (e.g., changes in immune function or reproductive physiology) as well as changes in condition and survival. Multi-year studies and long-term monitoring will be essential to detect chronic or long-term effects.
- Use the information gained from such studies to conduct formal assessments of risks, such as those of organochlorines to California sea lions.
- Identify new and emerging compounds and focus research on them, ranking them according to their potential for population-level impacts.
- Shift the focus of contaminant studies from documentation of contaminant levels to investigation of their effects.
- Conduct more studies of marine mammal feeding ecology and its implications for exposure to contaminants. These studies are particularly important for polar bears and should take advantage of sampling and other research opportunities using captive and hunter-killed bears. They are also needed for small cetaceans and sea otters, as recommended previously by the Marine Mammal Commission, the International Whaling Commission, and various workshops.
- Develop better tools and facilities for sample collection, diagnostics, archiving, and pooling or sharing of samples. Sampling methods (e.g., biopsies and scats) must be validated. The potential utility of extrapolation of contaminant effects among species or tissue types should be explored, with quantitative assessment of associated uncertainties.
- Use alternative means of access to tissue samples (e.g., from captive animals, stranded animals, animals killed by hunters, animals killed incidentally in fisheries). Animals whose source of mortality is known (e.g., those killed incidentally in fisheries) may provide important controls for animals whose source of mortality is unknown (e.g., some stranded animals).

- Reorient biomarker studies to emphasize mechanisms of action (linkages between exposure and observed effects), rather than only correlations.
- Explore the potential for epidemiological analyses of health histories and contaminant status of captive marine mammals.
- Compare reproductive rates in marine mammal populations with different contaminant levels in both adults and offspring.
- Establish an interdisciplinary team with relevant expertise on disease, harmful algal blooms, and contaminants. This team must be mobile and able to respond quickly to unusual events.
- Emphasize long-term research and monitoring.
- Support international efforts to monitor environmental contaminants (Arctic Monitoring and Assessment Program, United Nations, etc.) and link the U.S. list of emerging contaminants (Environmental Protection Agency) with those of international bodies.
- Formally evaluate the toxicological components, benefits, and risks to humans of consuming marine mammal products.

The need for evidence from controlled experimentation underlies many of the controversies surrounding contaminants and marine mammals. No definitive studies have been conducted that clearly elucidate cause-and-effect linkages between specific doses of specific chemicals and specific health outcomes in a marine mammal species.

Participants expressed a range of views regarding the value of extrapolating from controlled experiments to wild populations and from one species to another. Some felt that given the species-specific nature of responses, it would always be difficult to justify the latter. Also, much of what can be learned from whole-animal experiments can more easily (and less intrusively) be learned from in vitro experiments. Quantitative risk assessment is likely to be just as difficult with data from controlled experiments on model species as with data from in vitro experiments with the species of concern. Proponents of controlled experiments argued that a few carefully designed experiments with particular compounds, involving risk assessment experts in all phases of the design and analysis, would be highly informative. Also, the plausibility of extrapolations can be greatly improved by more rigorous evaluation of the differences and similarities between species, based on detailed review of the literature, supplemented where necessary by focused research on physiology and anatomy.

As a practical matter, controlled experiments are likely to be strongly opposed by some. Furthermore, such experiments cannot be conducted with wild marine mammal species, and individuals from many wild species cannot be brought into captivity. Therefore, it will be necessary to assess risks on the basis of inferences and extrapolations from a relatively few studies with model, or surrogate, species. An alternative approach to experiment-based risk assessment is to work from physiology-based models that provide plausible dose-response relationships, based upon data from whole-animal studies of model or surrogate species, in vitro experiments, and physiological and anatomical similarities.

Rehabilitated marine mammals that are not returned to the wild represent an underused resource for research and experimentation. Understanding of physiology, metabolic pathways of contaminants, and pharmacology could be greatly improved by studies using such animals as subjects, bearing in mind that they will have entered the rehabilitation facility with a wide range of pre-existing contaminant loads and, often, temporary or permanent disorders.

Another approach is to compare populations of the same species that live in regions with a sharp gradient of pollution levels, as has been suggested in the International Whaling Commission's Pollution 2000+ program of research. For example, it could be informative to compare the life history parameters, body condition, and other indices for a population of bottlenose dolphins living in a severely polluted bay with those of a bottlenose dolphin population living in an ecologically similar but less polluted area. Such studies must be carefully designed, and confounding factors need to be identified and accounted for to the greatest extent possible. The complete lack of experimental control is a fundamental and unavoidable shortcoming of such studies.

Finally, current efforts are not well coordinated or integrated. They continue to emphasize "traditional" chemicals of concern, e.g., organochlorines, organotins, and heavy metals. Although much remains to be learned about the persistence and effects of such chemicals, new and emerging chemicals must also be surveyed and investigated to identify new threats to marine mammals and marine ecosystems. Research priorities should be based on known or perceived risks in the same manner as cancer institutes rank chemicals as definitely not, possibly, probably, or definitely carcinogens. To improve the research-based screening of potentially harmful chemicals, the costs for research and screening of new chemicals should be borne by those who produce them. Research requirements should include the collection of information on the distribution, concentration, and persistence of chemicals that are being introduced (either deliberately or unintentionally) into the marine environment. Such information is essential for understanding the risks associated with contaminants and should be included in any scientific assessment of their effects.

Interactions with Other Topics

Contaminants need to be investigated and evaluated in conjunction with overall animal health and in relation to other stressors that are known or likely to be interactive. Contaminant-related issues are, therefore, especially amenable to intensive health assessment efforts and integrated, multidisciplinary research.

A centralized diagnostic and research support facility for studies of contaminants, disease, harmful algal blooms, noise, and other potential health-related stressors should be established (for details see Disease, above). Such a center can be physical (i.e., an actual building or network of buildings) or virtual (i.e., a coordinated network of individuals and teams working in a variety of locations and institutions). The center should be interdisciplinary. Wildlife health centers in Madison, WI, and Athens, GA, provide models. The goals of the center should include diagnostics, surveillance, research, predictive modeling, and communication to both scientific/technical and nonspecialist audiences (see Appendix E).

Harmful Algal Blooms

The Issue

The frequency of marine mammal die-offs in which harmful algal blooms are implicated as a causative factor appears to have increased in recent decades. Episodes of large-scale mortality in sea lions, dolphins, and southern sea otters along the California coast have been attributed to domoic acid outbreaks. Die-offs of manatees and bottlenose dolphins have been linked to brevetoxin produced by red tides in Florida. Saxitoxin is thought to have contributed to deaths of humpback whales in Cape Cod Bay and bottlenose dolphins in Florida's Indian River Lagoon. Ciguatoxins have long been suspected as a cause of mortality of endangered Hawaiian monk seals.

Although algal blooms are naturally occurring events, human activities have increased their frequency and severity. Nutrient loading of coastal waters, the inadvertent transport of harmful species of algae to novel places, and the ecosystem effects of overfishing can have a major influence. The role of human activities in facilitating algal blooms requires further investigation, as do possible means of prevention and mitigation. In particular, methods are needed for distinguishing blooms that result from human activities from those that result from natural causes. Such blooms pose threats not only to marine mammals but also to people who use the coastal zone, whether as a source of food (e.g., shellfish) or as an area of commercial, subsistence, or recreational activity. Marine mammal species and populations of either low abundance (e.g., North Atlantic right whales), restricted distribution (e.g., Florida manatees), or both (Hawaiian monk seals) may be particularly vulnerable to the effects of such blooms.

Needed Research

In view of the role of harmful algal blooms in marine mammal mortality and morbidity, research is needed to identify and implement management strategies to prevent their occurrence or at least mitigate their effects. Research is also needed to distinguish the effects of harmful algal blooms from other sources of mortality (e.g., disease, contaminants, and bycatch) and to determine if and how these different factors may interact. Complementary research on potentially affected marine mammals also is needed to ensure that involved populations are sufficiently abundant and dispersed to withstand such episodic events. This might be accomplished by incorporating bloom-related mortality into calculations of potential biological removal levels under the provisions of the Marine Mammal Protection Act.

More specific research questions to be addressed include the following:

- Are blooms occurring in areas where marine mammal populations are declining (assuming that monitoring has been adequate)?
- What are the basic (natural) causes of harmful algal blooms?
- What are the ecosystem effects of harmful algal blooms?
- What are the long-term effects on marine mammals of repeated exposure to the various algal toxins? For example, could impaired immune function in Florida manatees be linked to long-term, sublethal exposure to biotoxins?
- Have marine mammals developed behavioral or physiological mechanisms that enhance their tolerance of biotoxins?
- Do biotoxins interact and, if so, what are the implications for marine mammal health?

Specific recommendations from the consultation are the following:

- Undertake formal risk assessment to determine the long-term, population-level consequences of repeated exposure to domoic acid in California sea lions.
- Use existing analytical methods to estimate effect levels of brevetoxin exposure (from red tides) in manatees and bottlenose dolphins in Florida.
- Develop adequate detection methods to support an assessment of ciguateric fish in the reefs where Hawaiian monk seals forage.
- Conduct long-term research to document the occurrence (frequency), distribution, and extent of harmful algal blooms over time and space.

Views of participants differed on the question of whether there is credible evidence linking saxitoxin exposure (via consumption of copepods) to reproductive dysfunction in North Atlantic right whales. Potential for exposure during the summer feeding season could be evaluated by studying the spatial and temporal fluctuations of PSP (paralytic shellfish poisoning) toxin levels in the whales' main prey, the copepod Calanus finmarchicus, relative to the distribution of feeding right whales. It was agreed that the role of saxitoxin as a threat to right whales and other marine mammals should continue to be evaluated, but that more plausible hypotheses are available to explain the observed reproductive problems of the North Atlantic right whale population.

Risk assessment for California sea lions would require research input regarding harmful algal blooms to identify potential hazards, determine possible responses to different doses, and characterize the associated risks at the individual and population levels. The assessment would also require information on the size, status, and trends of the populations involved, and a multidisciplinary approach involving, for example, oceanographers, chemists, marine mammal biologists, toxicologists, physiologists, and ecologists (e.g., effects on prey).

More broadscale research recommendations include the following:

- Elucidate the relationship between harmful algal blooms and ocean/climate regimes.
- Integrate marine mammal–focused research into ongoing process-scale studies of harmful algal bloom dynamics (e.g., ECOHAB, the Ecology and Oceanography of Harmful Algal Blooms program), with the goal of generating predictive models. Understand-

ing of oceanography is important to determining the causes and dynamics of harmful algal blooms.
- Incorporate harmful algal blooms and marine mammal monitoring into existing and developing ocean-observing programs.
- Identify the types of human activities known or likely to cause or exacerbate harmful algal blooms (e.g., physical damage to coral reefs, trawling, and dredging). Elucidate the mechanisms that link these activities with the toxins, and rank their importance in terms of likely population-level impacts on marine mammals.
- Develop approaches for estimating total mortality caused by toxic algal blooms based on the number of carcasses that are actually observed.
- Establish and maintain long-term monitoring in areas where harmful algal blooms interact with marine mammals. The ability to detect mortality from biotoxin exposure is critically important.
- Examine correlations between marine mammal population declines and the frequencies and types of harmful algal blooms.
- Examine the chain of toxin transmission from algae to marine mammals (e.g., does biomagnification occur?).
- Improve methods of chemical detection and identification of algal toxins.
- Consider inclusion of marine mammal prey (indicator species) in food-safety monitoring programs.

Interactions with Other Topics

The potential interactions of harmful algal blooms with disease and contaminants were mentioned earlier, as was the need for these and other environmental stressors to be investigated and evaluated in an integrated and multidisciplinary manner (Appendix E).

Sound

The Issue

Hearing may be the primary sense by which marine mammals interpret and interact with their environment. Sound propagation in the ocean is remarkably efficient, much more so than in air. Humans are introducing more sound into the world's oceans each year. Marine mammals may be disturbed by anthropogenic sound, and such disturbance could interrupt important activities (e.g., nursing, resting), impair communication (by masking their signals), and even drive animals away from critical habitat (e.g., feeding grounds, migration routes). Under certain circumstances, sound also may physically harm and even lead to the death of marine mammals. Recently, mass strandings of beaked whales have been attributed to high-intensity noise from military ship sonars and airguns used for geophysical research. These strandings have heightened concerns regarding the effects of anthropogenic sound in the oceans.

Both the acute and long-term consequences of anthropogenic sound to marine mammal populations are poorly understood. Further research is essential to determine these effects and mitigate or eliminate those that are harmful. Effects that are not immediately lethal still may be significant and harmful if they lead proximally to changes in reproduction, migration or movement patterns, distribution, habitat use patterns for foraging, social behavior, communication, or lead to increased morbidity and mortality over longer time periods. The identification and assessment of such effects are a challenge because of the lack of baseline information and the complexity and expense of studying highly mobile animals in the marine environment. Such effects are, nonetheless, potentially important and even central to the controversy regarding the effects of anthropogenic sound on marine mammals.

Needed Research

The controversy regarding human-generated sound in the oceans is made more complex by the diversity of sound sources and types as well as by the variety of known or potential effects on the animals. Much of the noise that we introduce into the aquatic environment is an unintended byproduct of machine operations, but some of it is deliberate, either for a purpose unrelated to marine mammals or explicitly to influence marine mammal behavior. Anthropogenic sound sources include propeller cavitation and engines of ships and boats; sonar devices used by military personnel, fishermen, and scientists to detect objects or explore the ocean; air guns and other devices used for seismic profiling; offshore drilling rigs; explosives associated with construction or military activities; very loud acoustic deterrence devices intended to keep seals and sea lions away from aquaculture pens; and low-intensity but persistently operating pingers meant to prevent marine mammals from becoming entangled in fishing gear. Human-generated sound spans a wide range of frequencies and levels, and much of it is within the hearing range of marine mammals. Documented responses have included movement away from the source (ranging from rapid and obvious to slow and subtle), changed surfacing and diving behavior, and complete avoidance of an ensonified area. In recent years, humpback whales with fractured ear bones have been found near a marine construction site where explosives were being used, and numerous toothed cetaceans (particularly beaked whales) have come ashore (stranded) in areas where mid-frequency, high-intensity sonars were in use. Such observations have fueled concern that human-generated noise is not only having long-term effects on marine mammals by degrading their acoustic environment but also that it is having acute, lethal effects that could contribute to the depletion of some species and populations.

To address such concerns, extensive research will be needed on the great diversity of sound sources, sound types, and potential effects on the animals. The following research priorities were identified:

- Measuring and monitoring ocean sound
  - Collect, organize, and analyze historical marine anthropogenic noise data and identify changes in transport routes, oil and gas exploration sites, military activities, etc.
  - Develop and test global models for ocean noise, paying particular attention to changes in sound characteristics along continental shelves.
  - Report signal characteristics for anthropogenic noise sources, including new and emergent sources (e.g., jet-propelled ships).
  - Determine the relationship between anthropogenic activity level and noise level.
  - Initiate long-term ocean noise monitoring programs, including mapping of sound sources.

- Assessing effects of noise [including both acute (pulse) and chronic (cumulative, long-term, and "ambient")] on marine mammals
  - Investigate the causes of mass strandings, particularly those involving beaked whales.
  - Examine the effects of acute, high-intensity sounds on selected species of marine mammals. Make efforts to match exact sound components and levels of sound to their corresponding physiological or behavioral effects on the animals. Evaluate our ability to detect serious injury and mortality (i.e., what might we be missing?).
  - Obtain audiograms for additional species of marine mammals.
  - Distinguish between temporary and permanent damage to hearing (threshold shifts), and relate these to different types and

levels of exposure (e.g., distances from sound sources, environmental characteristics, animal behavior, etc.).
- Develop tools to study noise-related changes in behavior, physiology (including stress levels), and hearing capabilities of marine mammals in the wild, using opportunistic studies and controlled exposure experiments.
- Characterize marine mammal populations and critical habitat within areas of high-intensity sound generation.
- Conduct comparative studies of marine mammal populations in areas of low and high anthropogenic sound and use models to predict exposure to sound in areas of high noise generation and high marine mammal density.
- Determine population-level effects not only of acute events that involve injury or mortality but also of long-term, chronic exposure to noise.
- Conduct efficacy and cost-benefit analyses of different sound reduction and mitigation measures.
- Examine ecosystem effects of anthropogenic sound, including trophic effects.
- Develop approaches to describe and measure the cumulative effects of (1) multiple types of anthropogenic noise, and (2) noise in combination with other factors that affect marine mammals (e.g., hunting and offshore industrial activities).

- Use of acoustic tools
    - Explore ways of using sound to improve understanding of marine mammals.
    - Continue development of acoustic deterrents, always taking account of unintended side effects.
    - Reconcile the use of acoustic deterrents with the animals' foraging requirements and need for access to important habitats.

At the present time, one of the highest priorities is to improve understanding of the mechanisms involved in cetacean strandings associated with the use of sonar by the military and air guns by geophysical scientists. This will require expanded research on species about which very little is known, most notably Cuvier's beaked whale, the bottlenose whales, and the beaked whales of the genus Mesoplodon. Improved data are needed on the distribution, abundance, biology, and behavior of these species, especially in areas where potentially harmful sound sources are deployed (e.g., military exercises, seismic profiling, etc.). Experimental approaches to study the effects of high-intensity sound are essential but should be designed to avoid undue risk of harm to test subjects.

Assessment of risk needs to involve not only the beaked whales but also other species that may experience hearing threshold shifts (temporary and permanent), non-lethal injury, and deaths that may go undetected because they do not result in one or more carcasses appearing on shore. For risk assessment purposes, the total number of animals affected must be estimated from the observed number, keeping in mind that animals may be affected but not observed.

Research also must be conducted into methods for reducing noise levels, including the costs and benefits of such reductions. Initially, this research should focus on noise types that are identified as posing the greatest threat to marine mammals and marine ecosystems. Although the effects of sonar systems have been highly controversial, the effects of other noise sources may require equal attention. For example, the potential effects of seismic testing and the very loud sounds produced by large, fast vessels may have significant effects on marine mammals. The magnitude and extent of effects are, at present, poorly defined, and the efficacy of various measures in preventing adverse effects cannot be confidently determined. In the absence of clear, unequivocal evidence of adverse effects, few remedial measures have been required of the shipping industry and other producers of anthropogenic sound. The effects of underwater noise almost certainly depend on its characteristics (e.g., intensity or energy level, frequency, duration) and where and when it is produced (e.g., location, season). Without an improved understanding of such considerations, legislators and managers will have difficulty developing mitigation measures that target sound sources posing the greatest threat to marine mammals yet do not involve over-regulation.

The ability to detect marine mammals in an area of ocean is central to mitigation. For example, seismic work, sonar deployment, or military exercises could be managed with the goal of either selecting sites where no marine mammals are present or suspending operations until a specified area is determined to be at least temporarily devoid of marine mammals. However, given the difficulty of detecting some marine mammals, particularly those that are deep-diving or cryptic at the surface, such a strategy requires improved methods of detection (e.g., acoustic monitoring).

Interactions with Other Topics

Sound and bycatch are linked insofar as acoustic deterrents are widely used to reduce marine mammal bycatch. Acoustic harassment devices also have been used to manage conflicts between pinnipeds and aquaculture, and in at least some instances the conflicts are related to growing, or recovering, pinniped populations. Efforts to understand the causal processes involved in ship strikes often focus on sound (e.g., the capabilities of whales to detect and interpret the noise from an oncoming vessel). Also, acoustic methods and devices have been considered for alerting whales so that they can avoid being struck, or conversely, for enabling the vessel operators to detect and avoid whales in their path.

Stress from exposure to artificial sound may be additive or synergistic with other anthropogenic stressors, such as disease, contaminants, harmful algal blooms, environmental change, and poor nutrition (perhaps related to the effects of fisheries on key prey populations). Impaired acoustic abilities, whether from threshold shifts in hearing or from masking, could play a role in an individual marine mammal's susceptibility to bycatch in fishing gear or to being struck by a ship. Impaired ability to communicate using acoustic signals may also impede essential behavior of highly social marine mammals.

Ship Strikes

The Issue

Ship strikes constitute a threat to marine mammal populations, causing mortality and diminishing resilience to other threats. True rates of mortality and injury from ship strikes are difficult to estimate because unknown proportions of carcasses are not recovered and because the cause of death may not be evident when a carcass is found.

Many species experience some level of mortality from ship strikes, but the problem is most serious for populations that are small or already subject to other forms of stress, such as North Atlantic right whales and Florida manatees. The threat of ship strikes is likely to worsen as vessels increase in size and speed (e.g., with jet propulsion).

Background: This topic was not addressed by a background document but was discussed in plenary session after a presentation summarizing an article on ship strikes on whales by Laist et al. (2001). Although boat-related mortality and serious injury are also a significant and growing impediment to manatee recovery, the discussion focused on right whales, and the following points were raised:

- All sizes and types of watercraft are capable of colliding with whales (inflatables to submarines).
- The fate of a struck whale is usually correlated with the size of the vessel (e.g., ships >80m long are more lethal).
- The severity of a strike is also determined by the vessel's speed (>13 knots caused lethal injuries; <10 knots did not).
- Operators of vessels that had struck whales reported that they either failed to detect the animals beforehand or detected them too late to take evasive action.
- Whales often exhibit a last-second startle response, suggesting that they are unaware of the danger until it is too late to respond successfully.
- Initial results of controlled sound exposure studies have generally indicated that right whales do not respond to vessel approaches in ways that would reduce the risk of collision.

Needed Research and Management

Various measures to reduce the incidence and severity of ship strikes on right whales have been considered or implemented. These include the following:

- Canada has relocated shipping lanes in the Bay of Fundy to avoid areas heavily used by right whales, with the expectation of reducing ship strikes by 80 percent.
- Changes in routes and the imposition of speed zones have been considered in other areas of critical habitat for right whales. However, rerouting ship traffic is not always feasible because of insufficient water depths (e.g., on the coastal right whale calving ground in the southeastern United States) and lack of alternative approaches to a port (e.g., the right whale spring feeding ground in the Great South Channel).
- Aerial surveys have been conducted to locate whales and alert vessel operators who can then take appropriate action to reduce the likelihood of collisions.
- Technological solutions are being sought (e.g., alarms in ship's bows to trigger an evasive response on the part of the whales and sonars to allow ship's crews to detect whales at a sufficient distance to avoid hitting them).
- Public education and outreach programs have been conducted in both the United States and Canada.

The threat of ship strikes on right whales is urgent, and participants identified the following research priorities:

- Continue and expand mapping and analyses of vessel traffic patterns relative to right whale occurrence.
- Conduct compliance studies to determine the effectiveness of slow speed zones and other mitigation measures.
- Continue and expand studies to determine where ship strikes occur, which is difficult because carcasses may drift away from the collision site, be caught on the bows of ships (this usually applies only to the long-bodied Balaenoptera species), or not be observed and reported.
- Continue to explore the feasibility of forward-looking sonars to detect whales.
- Continue development of acoustic deterrents, bearing in mind any negative side-effects of introducing more sound into the oceans.

Technological solutions to the problem of ship strikes on whales have not been found. Aerial surveys are expensive, cannot be conducted at night or during bad weather, and would not represent a long-term answer to the problem even if real-time advisories to mariners were shown to be effective in preventing ship strikes. Judging by the observed behavior of right whales, solutions that depend upon the animals to anticipate and avoid collisions are not likely to work. Rather, the onus must be on the shipping industry as a whole, and on individual vessel operators, to change the way ship traffic moves through high-risk areas. The only approaches that look promising are to separate shipping activities from areas used by whales or to at least ensure that vessels slow down when they pass through such areas.

For manatees, insufficient attention has been given to the sub-acute, cumulative effects of injuries caused by vessel strikes.

Interactions with Other Topics

Ship strikes and sound are inextricably linked. Assuming that sound is the principal cue used by whales to detect and respond to an oncoming vessel, a trend toward quieter propulsion methods could at once lessen the problem of acoustic disturbance and worsen the problem of ship strikes. At the same time, efforts to decrease noise levels in the oceans could be expected to reduce the extent of masking and the degree of hearing impairment in marine mammals, with the effect of improving their ability to detect and avoid vessels. Global climate change in high latitudes is likely to extend the shipping season and make previously ice-bound areas accessible. This development will probably increase the risk of ship strikes for ice-associated animals (e.g., bowhead whales).

Growing (Recovering) Marine Mammal Populations

The Issue

Growing populations of some marine mammals, most of them recovering from past depletion, are competing for space occupied by a growing human population and, at times, disrupting human recreational and economic activities. This phenomenon, sometimes perceived and referred to as "overabundance" on the part of the marine mammals, is changing the attitudes of some people toward marine mammals. People who have regarded marine mammals favorably in the past are beginning to see them as pests to be controlled rather than as valued resources to be protected and conserved. Among the better-known examples are those involving (1) California sea lions that threaten an endangered run of steelhead trout at Ballard Locks in Seattle, (2) California sea lions that haul out on wharves in Monterey and San Francisco harbors, (3) harbor seals that haul out on a recreational beach at theChildren's Pool in La Jolla, California, and (4) manatees that are being hit by power boats. These and other conflicts between expanding human and marine mammal populations, both wishing to use coastal spaces and resources, are a growing management challenge.

Needed Research and Management

This subject was addressed only briefly during a plenary discussion. The following major points were identified:

- The issue should be defined not only in terms of changes in marine mammal behavior and increased marine mammal abundance but also in terms of human population growth and coastal development.
- Any effort to exclude marine mammals from an area needs to balance the risk that doing so could limit the population's recovery and jeopardize its future viability. A long-term perspective must be maintained, incorporating consideration of changes in ecosystems that may be contributing to the problem of "overabundance."
- The public differs on means to resolve this issue: some people enjoy (and thus benefit from) the presence of the animals (e.g.,

at Fisherman's Wharf or the Children's Pool) while other people may regard the animals as a nuisance.

- The Marine Mammal Protection Act provides for lethal removals of individual "problem" animals as a last resort under limited circumstances (pertaining to protection of threatened salmonid populations) and allows a suite of deterrence options to protect private property, personal safety, gear, and catch. It makes no provision, however, for reducing entire populations or for limiting the number of animals that are allowed to occupy a particular area. The waiver provision might apply if the population is above its optimum sustainable population level and is not likely to be disadvantaged by proposed removals.
- Conflicts of the kind considered here are almost always site- and context-specific so it may be unrealistic and counterproductive to seek a single, broadscale solution.
- These conflicts might be avoided by preventing seals and sea lions from establishing haul-out sites in certain areas. Such a proactive approach requires an ability to anticipate where pinnipeds are likely to expand their presence and to plan for their exclusion in advance.
- In designing research strategies to address this issue, it is important to distinguish between depredation (where marine mammals are viewed as plundering fishery catches; see Direct Effects, above) and situations in which marine mammals are competing with humans for space in the coastal zone.
- Keeping wild marine mammals and humans (including pets and livestock) spatially separated may have the added benefit of reducing the risk of disease transmission.

Two principal recommendations were developed to provide background information essential for regulatory, legislative, or judicial resolutions of these problems. The first is to review potential non-lethal approaches for excluding pinnipeds from haul-out sites and develop a set of management "tools." This review should consider the nature and scale of the problem, feasible options, the need for additional studies, and costs. It should result in a series of steps to address the problem (i.e., a plan of action).

The second recommendation is to convene a workshop that would consider and further develop the outcome of the review. Among the issues to be addressed are the following:

- Circumstances when lethal removals would be permitted. For example, would the marine mammal population need to be above its optimal sustainable population level?
- How to implement strategies for intervention (e.g., through a permitting process).

Habitat Degradation and Loss

The Issue

Habitat refers to the place where an organism lives and the resources that sustain it. Broadly interpreted, habitat encompasses the entire ecosystem upon which a species or population depends. Some marine mammals, such as harbor seals and Hawaiian monk seals, occupy a relatively well-defined habitat year-round; others, such as the migratory large whales, have a strong seasonal dimension to their habitat requirements. Some marine mammals have narrow feeding niches that restrict them to particular kinds of habitat (e.g., manatees need access to warm water and aquatic vegetation, sea otters and walruses must forage on benthic mollusks and crustaceans in shallow waters); others are relatively flexible and appear able to adapt to a fairly wide range of environmental conditions (e.g., coastal bottlenose dolphins).

Marine mammal habitat can be degraded in a number of ways (e.g., by the creation of large dead zones in coastal regions due to run-off of chemicals used in agriculture; loss of habitat for ice-dependent species as a result of climate change; greater incidence and severity of harmful algal blooms due to human-generated run-off; loss of sea grass beds due to trawling, dredging, and coastal construction; decreased prey availability due to competition with fisheries; and increased noise from shipping, sonar, and seismic testing). Southern resident killer whales in the Pacific Northwest may suffer from multiple forms of such degradation, including contamination of Puget Sound, loss of prey (salmon), and increased disturbance from noise generated by watercraft and coastal activities.

Although the preservation and restoration of marine mammal habitat are among the goals stated in various U.S. laws (e.g., the Marine Mammal Protection Act, the Endangered Species Act), most such legislation is unclear about what that means or how to achieve it. Without a better understanding of the natural (baseline) character, quantity, and quality of marine mammal habitat, and of the processes that have degraded and continue to degrade and destroy it, the legislative intent, and indeed the public will, to conserve that habitat will not be served.

Needed Research

Science must play a key role in developing a framework for habitat inventory, conservation, and management. However, the nature and extent of habitat needed to maintain marine mammal populations at optimum levels are not well understood. In addition, the effects of human activities on coastal and offshore habitat are inadequately monitored, understood, and appreciated.

A framework for the conservation and management of marine mammal habitat must address the following issues:

- Our ability to describe in a reliable, comprehensive, and quantitative manner the natural character of marine mammal habitat;
- The condition of that habitat and the extent to which it has been or is being modified by human activities;
- The mechanisms, significance, and interactions of threats to marine mammal habitat;
- Marine mammal response to changing environmental conditions; and
- The overall effectiveness of our existing system of habitat conservation.

Participants at the meeting identified the following research tasks as priorities:

- Conduct a systematic review of knowledge of marine mammal distribution and movement patterns in order to identify gaps in knowledge and needed research.
- Describe the natural distributions of marine mammals and investigate how those vary over time or as a function of other natural factors (e.g., oceanic conditions, forage base).
- Identify the essential features of marine mammal habitat, investigate their character and variability over space and time, and relate them to species' sensory biology and life history.
- Seek a thorough and rigorous description of action areas where the potential exists for human activities to affect marine mammal habitat, including indirect and downstream effects.
- Where habitat has already been modified substantially, devote research and management effort to habitat restoration.
- Support large-scale (ecosystem-level), long-term (on a scale of decades rather than years) studies that consider multiple causes of habitat change.

- Develop multivariate tools that make it possible to assess cumulative or otherwise interactive effects of a variety of human activities on marine mammal habitat.

The following concerns should be kept in mind as those research tasks are pursued:

- In many instances, marine mammal habitat will have been altered significantly before any effort was made to collect baseline data. In such circumstances, care must be taken to avoid accepting current conditions as the baseline.
- Information conveyed to decision-makers must include an assessment of the associated level of confidence (statistical power) in describing habitats and various forms of habitat loss.
- The use of marine protected areas as controls in studies of habitat degradation can be confounded if (1) human effects are already apparent, (2) recovery is needed before the protected area can be considered "undisturbed," or (3) the protected area designation was made out of concern for a single species without taking account of multispecies ecological relationships.

Elements that should be included in a framework for habitat conservation are the following:

- Specific, measurable goals and objectives that reflect society's general intent as stated in relevant legislation.
- A comprehensive strategy for achieving those goals and objectives (including establishment of marine protected areas).
- A strong intellectual foundation based on ecosystem science and community ecology.
- Defined habitat management units that can be characterized qualitatively and quantitatively and that can be used to facilitate the collection of baseline data, identify priority areas for research, and assess threats.
- The collection of baseline information.
- Descriptions of key issues, problems, or threats that must be addressed to manage and conserve habitat.
- Comprehensive, multivariate, multidisciplinary research programs.
- Comprehensive assessments of human effects, including downstream effects, ensuring that all such assessments are accompanied by explicit consideration of statistical power and alternative hypotheses.

- Comprehensive summary statistics that are understandable to scientists, managers, decision-makers, and the public—yardsticks showing the extent of habitat loss and any progress made toward habitat protection and restoration.
- Guidance for restoration efforts.
- Feedback mechanisms for assessing the efficacy of conservation strategies.
- Adaptive mechanisms for modifying the framework as new information becomes available.
- Resources to develop and implement the framework, bearing in mind that the burden of paying for assessment and remediation should be borne largely by the proponents of activities that degrade or destroy habitat.

Interactions with Other Topics

This topic overlaps in many ways with long-term environmental change. The challenge of distinguishing between "natural" and human-caused environmental variability is common to both, as is the need for good baseline data; large-scale, long-term, multivariate studies (including experimentation and the use of "control" areas); and monitoring. Habitat degradation is also related to or occurs as a result of human population growth, demography, and consumption; discharge of pollutants into fresh and marine waters; coastal development; fishery removals and destructive fishing practices (e.g., bottom trawling); and introduction of anthropogenic sound into the underwater environment. Basic knowledge of animal biology, phenology, physiology, behavior, health and nutrition, and ecology is central for this topic as for many of the others. Population management units may or may not match up with habitat management units, but the two concepts should be explored in tandem. The decision rules for conservation management pertaining to population recovery or maintenance need to integrate consideration of habitat modification, whether in the past, present, or future.

Long-term Environmental Change

The Issue

Marine mammals have always lived and evolved in a changing environment, and their populations have likely fluctuated over long time scales in response to such change. For example, the alternate warming and cooling of the Arctic regions over periods of hundreds or thousands of years have influenced ice conditions in the straits and channels used as migration routes by bowhead whales. These long-term pulses in ice coverage have affected the whales' access to different areas, at times fragmenting the overall population and at other times allowing the whales to mix much more widely. This dynamic aspect of marine mammal populations has often been either unrecognized or poorly understood, and often it has been assumed that their size and distribution would be essentially constant in the absence of anthropogenic disturbance.

The recent declines in some marine mammal populations in Alaska have occurred during a period when there have been large-scale regime shifts in the North Pacific Ocean and

Bering Sea. Farther south in the Pacific, some fur seal populations have lost entire cohorts of pups during severe El Niño events. Together with broad concerns about global warming, these developments have created a sense of urgency about improving our understanding of long-term environmental changes and their implications for marine mammals. Two questions are central to these concerns. The first is how, and to what degree, human activities contribute to the processes driving such events. The second is whether and to what extent marine mammals are more vulnerable to the effects of human activities due to variation in environmental conditions.

Needed Research

Policy decisions must be informed by an understanding of the long-term and long-range consequences of human activities. However, on long time scales (decades and longer) and at the ecosystem level, distinguishing between natural change and human-caused change is extremely difficult. An individual animal responds to its proximate or immediate environment, regardless of the ultimate cause of any change in that environment (i.e., whether natural or anthropogenic). The scientific challenge, therefore, is to obtain insights about human-induced impacts through experimentation, monitoring, and analysis. These insights, when combined with data on natural environmental variability, can then be used to make credible predictions of the direction and magnitude of long-term environmental change, whether natural or anthropogenic, and the consequences of those changes to marine mammals. Spatial and temporal scale is a key factor in such research.

The duration of most marine mammal research has been too short to support inferences concerning animal responses to long-term environmental change. Similarly, the spatial scale of most marine mammal studies has been limited in relation to the scale at which environmental change occurs. Even the few programs that are truly large-scale and long-term are inadequate in some respects. For example, the time series of tuna-dolphin surveys in the eastern tropical Pacific began when a regime shift was already underway. Moreover, there is an eight-year gap in the middle of that time series, and funding for surveys in that region continues to be on a year-to-year basis.

The annual federal funding cycle is antithetical to effective study of long-term environmental change. It is unrealistic to expect meaningful results from programs that are reevaluated for continued funding on an annual basis. Issues such as the greenhouse effect must be addressed on a time scale of many tens if not hundreds of years. The well-known oscillatory pattern in the eastern Pacific, involving shifts between a cold regime and a warm regime, was only recognized once a multi-decadal perspective was possible. This does not mean that every long-term problem must be addressed through annual surveys or continuous monitoring. It does mean, however, that study designs need to be premised on a long-term view, and that sampling needs to be planned for, and feasible, at regular intervals through time. Tiered funding may be a useful approach. For example, one tier could support intensive, hypothesis-driven research over a ten-year period, while a second tier provides for monitoring of selected variables at multi-year intervals over the long term (e.g., 100 years).

Large programs in marine science ("ocean observing") afford needed opportunities to monitor marine mammals as well as the physical and biological processes that underlie their existence. These programs provide logistical support and infrastructure, ancillary data and, importantly, the information needed to understand long-term, broad-scale ecosystem processes. A number of such programs are underway or in an early stage of development (Appendix F). The California Cooperative Fisheries Investigations (CalCOFI) program, initiated in 1951 and still operating, provides a model of broad-scale, long-term sampling that may be unique in the world. Programs similar to CalCOFI should be initiated for at least one or two other large marine ecosystems in which marine mammals play a prominent role (e.g., Gulf of Maine, Gulf of Alaska, and North Pacific frontal zone). If similar time series had been available for the Bering Sea/Gulf of Alaska region, for example, the recent puzzling declines of certain marine mammal populations there (e.g., Steller sea lions, harbor seals, and sea otters) likely would have been detected earlier, if not predicted before they began, and the underlying causes would be better understood and perhaps even mitigated.

The creation and maintenance of ocean observing systems provide two important opportunities. The first is to incorporate or expand marine mammal monitoring into existing protocols (e.g., for fisheries, shipping, and meteorology; see Appendix F). The second is to initiate long-term monitoring programs with a focus on regions of particular importance to marine mammals. Such multidisciplinary research programs offer benefits to all involved areas of research, as studies of marine mammals provide insights into oceanography, fisheries, etc., and studies of these other topics help explain the distribution, abundance, and behavior of marine mammals. The distribution and movement patterns of marine mammals (especially whales) have been used to select oceanographic sampling sites for cruises conducted as part of the Global Ocean Ecosystem Dynamics (GLOBEC) program. Recently, successful experiments have been carried out using instrumented marine mammals as platforms for collecting oceanographic data. By linking marine mammal observations to concurrent measurements of physical features and observations of other biota within the context of an ongoing monitoring program, marine mammalogists become better able to correlate variability and infer causal connections. Such information provides insights into the dynamics and behavior of marine mammals in variable environments and an essential reference for assessing the effects of human activities.

Research programs investigating the relationships of marine mammals to their biotic and abiotic environment must—

- Be long-term and geographically broad to ensure that they are appropriately scaled to investigate those relationships and their inherent variability over time and space.
- Be multidisciplinary to ensure the incorporation of all pertinent factors (e.g., physical oceanography, prey availability, other related species including economically valued species and those that are not of economic value).
- Have sustained or long-term funding to ensure that they are carried through to completion. Programs that provide data for fisheries management, improve understanding of ecosystem dynamics, and address the conservation of high-profile species such as marine mammals, turtles, and sea birds are most likely to attract such funding.
- Be cognizant of and adapted to the natural variation among the marine mammals being investigated. For example, monitoring

of abundance of Antarctic minke whales may be more difficult because they are cryptic and widely dispersed, whereas trends in pinniped populations may be more easily assessed because of their haul-out patterns.

- Be logistically feasible.
- Build on information from previous studies.
- Address identified needs. Because the effects of global warming are amplified at the poles, studies of the effects of long-term environmental change on Arctic and Antarctic marine mammals may take precedence. Similarly, international agreements pertaining to a region (e.g., the Convention on the Conservation of Antarctic Marine Living Resources) or taxonomic group (e.g., the Agreement on the Conservation of Polar Bears) can facilitate the leveraging of funds and help legitimize long-term environmental research and monitoring.

Research needs and priorities identified were as follows:

- An inventory of ocean monitoring programs and long-term databases and assessment of (1) the value and feasibility of adding a marine mammal focus to programs that do not already have one, and (2) the potential for retrospective analyses ("hindcasting") using archived data.
- Participation by marine mammal biologists in program planning and research design (e.g., what variables are to be measured, sampling protocols).
- Sources of sustained funding.
- Identification and focus on priority ecosystems, with associated collection of needed long-term physical and biological oceanographic data.
- More studies of the behavioral ecology of marine mammals to provide a better basis for hypothesis formulation and data interpretation.
- Methods to integrate large, multivariate data sets (e.g., modeling) and generate predictions that can be tested by long-term monitoring.
- Development of better tools to characterize environmental variables over space and time (e.g., passive acoustics, satellite telemetry, and remote sensing).
- Integration and analysis of data sets from multiple time scales, ranging from seasonal episodic events to multi-decadal (long-term) average conditions.
- Means for archiving biological samples.

Interactions with Other Topics

The topic of long-term environmental change is closely related to many of the other topics considered in the consultation. Data collected in long-term monitoring programs can also be used to address questions related to those topics. For example, data on water temperature, salinity, and stratification are useful not only to track environmental changes that could affect marine mammals but also to predict the occurrence of harmful algal blooms or outbreaks of disease, the dispersal of pollutants in coastal waters, or patterns of sound transmission and exposure of marine mammals to noise. Underwater sound is one of the variables that would be useful to measure directly as part of standard oceanographic sampling protocols. Moreover, underwater acoustic thermometry, one of the tools used to study the ocean environment, is itself a source of anthropogenic sound with potential effects on marine mammals.

Many of the same types of data that are needed as input to models of indirect fishery interactions are also central to models of long-term environmental change. For example, data on abundance and distribution of invertebrate, fish, and marine mammal populations are needed, as is a good understanding of the trophic and other ecological relationships among them. Changes in the quality and quantity of marine mammal habitat are closely linked to long-term environmental change, and the former may serve as a good measure of the latter. Finally, decision rules for management should be flexible enough to incorporate information on long-term environmental change as well as the many other factors affecting the status of marine mammal populations.

Units to Conserve

The Issue

The Endangered Species Act and Marine Mammal Protection Act reflect society's desire to preserve biological diversity and maintain healthy ecosystems. Contrary to the widespread assumption that conservation need only be directed at the species level, both of the acts recognize that species consist of populations or population structure that is essential both to the evolutionary persistence of those species and to fully maintaining their roles in ecosystems. Understanding the population structure inherent in species and the ecological significance of that structure is, therefore, essential for identifying management units for conservation.

Killer whales in the Pacific Northwest provide an example of the need to understand the biology and stock structure within a species to provide a basis for conservation efforts. These animals occur as at least three genetically distinct types: resident, transient, and offshore. Although the different types of killer whales overlap somewhat in distribution, they are distinctive in many important respects, including their prey (e.g., fish vs. marine mammals), behavior (e.g., vocal dialects), and social organization (e.g., group size). A recent proposal to list the "southern resident" group in the Puget Sound/San Juan Islands region as endangered has drawn attention to the difficulties involved in defining "distinct population segments" under the Endangered Species Act. Although genetic differences exist between this and other killer whale groups, deciding whether the disappearance of southern residents would represent a "significant" loss in evolutionary terms has been confounded by the fact that the taxonomy of the killer whales is in flux, with uncertainty about whether there is one or more than one species or subspecies.

Defining "population stocks" under the Marine Mammal Protection Act has also been difficult. One of the major challenges is to delineate conservation units that will ensure the continued occupation of a population's range, and thus its function in the ecosystem. [If populations overlap in range but differ in function (e.g., resident vs. transient killer whales), then you cannot maintain their ecosystem function simply by maintaining range on a "species" basis.] Harbor seals in Alaska provide another example. Only three management stocks of harbor seals are currently recognized in Alaska, but genetic analyses have revealed at least 12 demographically distinct groups. Some of these groups are declining and are subject to subsistence hunting. These demographically distinct groups are at increased risk of extinction if they are managed as only three stocks. Improved understanding of population structure would make it possible to focus conservation resources more precisely upon units that are truly at risk and would provide greater assurance that ecosystem function is, in fact, conserved.

Needed Research

Taxonomy—Taxonomy is a generally conservative field. Strict rules must be followed to establish the validity of a species. Decisions to split one species into two, or to combine two into one, are made cautiously and are therefore time-consuming. A particular problem arises with animals, such as many marine mammals, for which large, representative series of specimens are not readily available. In fact, in several instances involving cetaceans, species-level differences are known to exist, but formal naming of new taxa must await the availability and analysis of larger samples (e.g., killer and minke whales). Considering the rapid rate of environmental change and the speed with which long-lived, slow-reproducing animals like marine mammals can be depleted by hunting or incidental mortality, adherence to classical taxonomic procedures for defining and naming units to conserve may not be appropriate.

The following actions or processes would reduce the danger that uncertainties in taxonomy will result in bad decisions about units to conserve:

- List and rank the taxonomic uncertainties for marine mammals.
- Develop a method for provisionally recognizing unnamed taxa pending the acquisition and analysis of additional data (e.g., designate "formally undescribed but recognized species").
- Systematically fill data gaps according to the priorities established under the first bullet point, above.
- Produce a means of defining units to conserve under both the Endangered Species Act and the Marine Mammal Protection Act that explicitly incorporates the treatment of uncertainty and that embodies a precautionary approach.
- Maintain a strong public commitment to support expertise in taxonomy and systematics, which remain cornerstones of conservation biology.

Several of those tasks will best be undertaken in a workshop framework, while others will require support to individuals or teams of researchers who develop and performance-test new analytical approaches.

Ecosystem function—Any definition of a unit to conserve implicitly includes a spatial component (i.e., the geographical range occupied by that unit). Historical information, when available, provides guidance in this regard. In many instances, exploitation has not only reduced the number of animals but also caused their range to contract. Knowledge about historical distribution can help shape our expectations for recovery by establishing where the core and peripheral portions of the range were and where they likely would be if the population were allowed to recover fully. Northern elephant seals in California are in the process of recolonizing core parts of their former range, while large whales remain absent or very scarce in some areas of past abundance (e.g., humpback whales in New Zealand coastal waters, blue whales around South Georgia in the South Atlantic Ocean). Besides the effects of sheer numerical depletion, the loss of cultural memory within an animal population could be an important factor inhibiting the species' return to core portions of its range. Recolonization of traditional habitat may then depend upon chance events as groups of animals living on the edges of that depopulated portion of the range disperse and rediscover the formerly occupied habitat de nouveau.

The following needs were identified with regard to the problems of defining conservation units to maintain and restore range and ecosystem function:

- Develop better analytical tools to design studies of population structure. For example, methods to estimate, in advance, how many samples and how many genetic markers will be needed to provide a given level of certainty about dispersal rates would make research planning and budget decision-making much more efficient.
- Develop approaches for identifying units to conserve through the integration of data on distribution, movement patterns, trends in abundance, contaminant levels, morphology, timing of migration and reproductive events, behavior (including acoustics), and genetics.
- Increase attention to, and invest more resources in, the collection of tissue samples for genetic analyses, with emphasis on areas or species at greatest risk from known threats.
- Ensure that suitable institutional arrangements are in place to archive tissue samples and related data on a permanent, and preferably centralized, basis.
- Anticipate problems regarding units to conserve and initiate necessary work in advance of crises. For example, if, as predicted by the United Nations Food and Agriculture Organization, cephalopod fisheries are going to expand rapidly in coming decades, conservation problems involving squid-eating marine mammals are likely to arise. Sampling and analysis strategies for these species should be initiated immediately.
- Increase coordination between investigations of units to conserve and stock assessment reports.

Interactions with Other Topics

Assessment of any threat at the "population level" requires some notion of the unit to conserve, whether it is a species, subspecies, biological population, or management stock. Therefore, this topic is highly relevant in the context of assessing risks from disease, sound, contaminants, harmful algal blooms, bycatch, ship strikes, habitat modification, and environmental change more generally. An understanding of population structure (units to conserve) is central to risk assessment.

Strong interaction exists between defining units to conserve and developing frameworks for management decision-making (the following section of this report). Taxonomic and other distinctions (e.g., distinct population segments) should be made using predetermined processes with as little discretionary latitude as possible.

The Science of Management

The Issue

Management policy is intended to govern the way human activities affect the natural environment, including how the benefits derived from living resources are used and distributed. In the light of expected changes in human population size, consumption, and demography in the coming decades, a robust decision-making framework will be necessary to achieve the policy goals of conserving marine mammal populations and habitat. Such a framework must have a rigorous and appropriate analytical underpinning. This latter requires a substantial investment in research to develop an array of decision rules that satisfy explicit quantitative standards and assure predictable implementation in the face of competing visions and economic interests.

Years of scientific effort were required to establish an operational definition of “optimum sustainable population” (OSP) under the Marine Mammal Protection Act and to devise a decision rule (“potential biological removal,” or PBR) to ensure that incidental mortality caused by commercial fishing operations would not prevent marine mammal populations from recovering to, and remaining at or above, their OSP levels. Further work of this kind is needed to address other challenges, both present and future. For example, the questions of protecting habitat and ecosystem productivity under the Marine Mammal Protection Act have yet to be addressed through a similar process. Nor has sufficient attention been given to implementation of the Endangered Species Act, whether in terms of adopting consistent quantitative standards, clarifying the population units that are the objects of protection, or incorporating scientific uncertainty into “jeopardy” and “adverse modification” determinations.

Needed Research

New or improved decision rules are needed for all four of the U.S. laws most relevant to marine mammal conservation and management: the Endangered Species Act, the Marine Mammal Protection Act, the National Environmental Policy Act, and the Fisheries Conservation and Management Act. Consistent quantitative standards should be developed for the following:

- Endangered Species Act listing decisions (e.g., endangered, threatened).
- Endangered Species Act jeopardy and adverse modification determinations (i.e., critical thresholds for deciding that a proposed action will not "jeopardize the continued existence" or "adversely modify the critical habitat" of a listed population).
- Determinations of "critical habitat" under the Endangered Species Act.
- Defining "reasonable and prudent alternatives" to proposed actions that have been judged to pose jeopardy or adverse modification under the Act.
- Decisions to invoke experimentation as a reasonable and prudent alternative under the Act.
- An adaptive framework to measure success (and thus delisting rationales) for Endangered Species Act "recovery plans."
- Marine Mammal Protection Act judgments concerning "negligible" consequences of a given level of take.
- Determinations of "optimum sustainable population" in conditions of declining carrying capacity.
- The ecosystem protection provisions of the Fisheries Conservation and Management Act.
- Determinations of "significant impacts" for environmental assessments under National Environmental Policy Act and guidelines for analyses of effects in environmental assessments and environmental impact statements.

Participants in the consultation concluded that a good decision rule must do the following:

- Be both practical and intelligible.
- Satisfy essential standards inherent within the underlying policy (i.e., contain a statement of the desired effect and an error tolerance for achieving it).
- Operate entirely (or as much as possible) from objective data inputs.

- Make use of as much relevant data as is available.
- Incorporate a margin of safety (for dealing with uncertainty) that reflects society's values (presumably embodied in the relevant legislation).
- Minimize discretionary latitude in decision-making.
- Reflect a professional consensus concerning its technical (analytical) aspects.
- Sustain thorough performance testing, initially with models and later through implementation on an adaptive basis.
- Anticipate future trends (e.g., long-term environmental change, habitat modification, and increased competition for fishery resources).

One extremely valuable side benefit of a good decision rule is that it provides an automatic incentive to collect more data when implementation costs are high because of uncertainty surrounding a decision.

In addition to the specific needs for quantitative standards listed above, Endangered Species Act implementation would benefit from the development of a method similar to PBR for population viability analysis (i.e., determining whether a given set of management interventions will assure a specified probability of population persistence over a given future time frame). Ideally, such a decision-making framework would be developed through a case study approach involving a marine mammal species (e.g., a large whale) for which there is minimal ambiguity in regard to population structure, as well as good quantitative information on abundance, life history, human-caused mortality, and other factors.

Elements that should be addressed by this new analytical framework for the Endangered Species Act include the following:

- Incorporation of spatial complexity, possibly using a series of models, each tailored to a different type of population structure (e.g., panmixis, cascading, etc.).
- Incorporation of appropriate population structure, including metapopulation dynamics.
- Minimization of discretionary latitude (e.g., by standardizing judgment calls, as intended with the recovery factor in PBR).
- The wide range of time scales necessitated by the long life spans of some marine mammals and the diversity of species covered by the Endangered Species Act. In this regard, it might be preferable to express criteria and thresholds in terms of generations rather than years.

- Future changes in environmental conditions.

Participants generally supported the idea of using a Bayesian approach to population viability analysis modeling, with starting parameter information incorporated in so-called "prior" distributions, or "priors." Default values would be used when case-specific data are not available, but when such data are available they would be incorporated by simply adjusting the priors. A set of rules would be needed to guide development of default priors and evaluate sensitivity to them, establish criteria for assessing the quality of data, and create mechanisms to ensure that required data are collected.

Implementation of Decision Rules

Getting public support, and in turn the support of policy makers, for quantitative, standardized decision rules is a further challenge. How such rules are illustrated and communicated is key to their acceptance and, thus, their ultimate effectiveness. The rules must be transparent and comprehensible to achieve and sustain a policy consensus. Some tension can nevertheless be expected to remain between the intent of decision rules to minimize discretionary latitude and the desire of managers for flexibility in regulatory implementation.

Decision rules developed for use on species in U.S. waters may have international implications. Many marine mammal populations occur in more than one country and therefore require conservation management at an international, or at least bilateral or regional, level. The International Whaling Commission provides a mechanism for meeting that requirement with respect to whales and whaling, and various commissions and agreement bodies exist to cover other species and types of human-marine mammal interaction. Where such bodies exist, they may provide opportunities for adaptation and application of the decision rules developed initially to facilitate implementation of U.S. laws. For example, although the PBR formula has not been incorporated directly into the decision-making framework of the IWC, it has provided a focus for discussions of particular issues within the IWC Scientific Committee. Also, it has been cited and applied in an ad hoc manner by at least one multilateral conservation agreement (ASCOBANS, the Agreement on Small Cetacean Conservation in the Baltic and North Seas) and by national government agencies in other countries (e.g., the Canadian Department of Fisheries and Oceans to set catch limits for bowhead whales).

Interactions with Other Topics

A close methodological connection exists between the development of management decision rules and the development of definitions of units to conserve. Another obvious link exists with direct fishery interactions, as the flagship PBR decision rule was developed specifically to manage bycatch. Consideration of the effects of many different types of threat, including disease, sound, contaminants, harmful algal blooms, direct and indirect fishery interactions, ship strikes, habitat modification and loss, and long-term environmental change is expected to be integrated, either explicitly or as part of stochastic variation, in any acceptably rigorous decision rule of the kind envisioned here.

Section IV. Appendices

Appendix A. Participants in the Consultation

Vera Alexander
University of Alaska
Fairbanks, Alaska

Jay Barlow
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

Daryl Boness
Smithsonian Institution
Washington, DC

Ian Boyd
Gatty Marine Laboratory
University of St. Andrews
Scotland

Robert Brownell, Jr.
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

Douglas Butterworth
University of Capetown
South Africa

Dave Checkley, Jr.
University of California
San Diego, California

Philip Clapham
Northeast Fisheries Science Center
National Marine Fisheries Service
Woods Hole, Massachusetts

David Cottingham*
Marine Mammal Commission
Bethesda, Maryland

Tara Cox*
Marine Mammal Commission
Bethesda, Maryland

Paul Dayton*
Scripps Institution of
Oceanography
La Jolla, California

Anne Fairbrother
U.S. Environmental Protection
Agency
Corvallis, Oregon

Megan Ferguson
University of California
San Diego, California

Bridget Ferris
Senate Commerce, Science, and
Transportation Committee
Washington, DC

Nicholas Gales
Australian Antarctic Division
Australia

Steven Ganey
Regional Marine Conservation
Project
Portland, Oregon

Daniel Goodman
Montana State University
Bozeman, Montana

Michael Gosliner
Marine Mammal Commission
Bethesda, Maryland

Frances Gulland
The Marine Mammal Center
Sausalito, California

Ailsa Hall
Gatty Marine Laboratory
University of St. Andrews
Scotland

John Harwood
Gatty Marine Laboratory
University of St. Andrews
Scotland

John Hildebrand
Scripps Institution of Oceanography
La Jolla, California

Henry Huntington
Huntington Consulting
Eagle River, Alaska

Craig Johnson
National Marine Fisheries Service
Silver Spring, Maryland

Darlene Ketten
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

David Laist
Marine Mammal Commission
Bethesda, Maryland

David Lavigne
International Fund for Animal Welfare
Guelph, Ontario, Canada

Lloyd Lowry
Marine Mammal Commission
Kailua-Kona, Hawaii

Robert Mattlin*
Pacific Institute for Marine Wildlife Research
Upper Moutere, New Zealand

Suzanne Montgomery*
Marine Mammal Commission
Bethesda, Maryland

Sue Moore
National Marine Mammal Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
Seattle, Washington

Todd O'Hara
North Slope Borough
Barrow, Alaska

Thomas O'Shea
U.S. Geological Survey
Fort Collins, Colorado

Daniel Pauly
University of British Columbia
Vancouver, British Columbia, Canada

William Perrin*
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

Timothy Ragen*
Marine Mammal Commission
Bethesda, Maryland

Andrew Read
Duke University Marine Laboratory
Beaufort, North Carolina

Randall Reeves*
Okapi Wildlife Associates
Hudson, Quebec, Canada

Stephen Reilly
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

John Reynolds, III*
Marine Mammal Commission
Mote Marine Laboratory
Sarasota, Florida

Lorenzo Rojas-Bracho
Instituto Nacional de Ecología
San Ysidro, California

Andy Rosenberg
University of New Hampshire
Durham, New Hampshire

Teri Rowles*
Hollings Marine Laboratory
Charleston, South Carolina

Brent Stewart
Hubbs Sea World Research Institute
San Diego, California

Barbara Taylor
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

Michael Tillman
Southwest Fisheries Science Center
National Marine Fisheries Service
La Jolla, California

Whitney Tilt*
National Fish and Wildlife
Foundation
Bozeman, Montana

Frances Van Dolah
National Ocean Service
Charleston, South Carolina

Douglas Wartzok
Florida International University
Miami, Florida

Gunter Weller
University of Alaska
Fairbanks, Alaska

Dana Wetzel
Mote Marine Laboratory
Sarasota, Florida

* Steering committee member

Appendix B. Common and Scientific Names of Vertebrate Animals Used in this Report

Antarctic minke whale	*Balaenoptera bonaerensis*
Beaked whales	Ziphiidae
Beluga whale	*Delphinapterus leucas*
Blue whale	*Balaenoptera musculus*
Bottlenose dolphin	*Tursiops truncatus*
Bottlenose whales	*Hyperoodon* spp.
Bowhead whale	*Balaena mysticetus*
California sea lion	*Zalophus californianus*
Cod	*Gadus morhua*
Cuvier's beaked whale	*Ziphius cavirostris*
Fin whale	*Balaenoptera physalus*
Gray seal	*Halichoerus grypus*
Gray whale	*Eschrichtius robustus*
Harbor seal	*Phoca vitulina*
Harp seal	*Pagophilus groenlandiusa*
Hawaiian monk seal	*Monachus schauinslandi*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Manatee	*Trichechus manatus*
Minke whale	*Balaenoptera acutorostrata*
North Atlantic right whale	*Eubalaena glacialis*
North Pacific right whale	*Eubalaena japonica*
Northern elephant seal	*Mirounga angustirostris*
Polar bear	*Ursus maritimus*
Ringed seal	*Pusa hispida*
Sablefish	*Anoplopoma fimbria*
Sea otter	*Enhydra lutris*
Sperm whale	*Physeter macrocephalus*
Steller sea lion	*Eumetopias jubatus*
Vaquita	*Phocoena sinus*

Appendix C. Authors and Titles of Background Papers

Direct Fishery Interactions

Read, A. J. Direct Interactions between marine mammals and fisheries.

Indirect Fishery Interactions

Plagányi, É. E., and D. S. Butterworth. Indirect fishery interactions: Assessing the feeding-related interactions between marine mammals and fisheries.

Disease

Gulland, F .M. D., and A. J. Hall. The role of infectious disease in influencing status and trends in marine mammal populations.

Contaminants

O'Hara, T. M., and T. J. O'Shea. Contaminants in marine mammals.

Harmful Algal Blooms

Van Dolah, F. M. Effects of harmful algal blooms on marine mammals: Information needs and prospects for management.

Sound

Hildebrand. J. Marine mammals and sound.

Habitat Degradation and Loss

Ragen, T. J. Habitat Transformation: The nature of loss and the loss of nature.

Long-term Environmental Change

Moore, S. E. Effects of long-term environmental change on marine mammals.

Units to Conserve

Taylor, B. L. Deciding on units to conserve in the face of uncertainty.

The Science of Management

Goodman, D. Adapting the management of marine mammals to cope with future changes.

Appendix D. Agenda of the Consultation meeting

Consultation on Future Directions in Marine Mammal Research

Marine Mammal Commission
in collaboration with the
National Fish and Wildlife Foundation
Portland, Oregon
4–7 August 2003

4 August (Monday)

8:00	Welcome (Chair, John Reynolds) Introduction to the consultation process (Tony Faast) Review of consultation objectives Presentation of Session A background papers (approximately 20 minutes each). Plenary discussion (10 minutes each) limited to clarifying remarks of interest to full gathering.
9:00	**The role of infectious disease in influencing status and trends in marine mammal populations** Frances M.D. Gulland and Ailsa J. Hall
9:30	**Marine mammals and sound** John Hildebrand
10:00	Break
10:15	**Contaminants in marine mammals** Todd M. O'Hara and Thomas J. O'Shea
10:45	**Effects of harmful algal blooms on marine mammals: Information needs and prospects for management** Frances M. Van Dolah
11:15	Break for Lunch
1:00	Issue discussions by each of four break-out groups
5:00	Adjourn for the day

5 August (Tuesday)

8:00	Plenary review of reports from discussion groups Presentation of Session B background papers
9:30	**Direct interactions between marine mammals and fisheries** Andrew J. Read
10:00	Break
10:15	**Indirect fishery interactions: Assessing the feeding-related interactions between marine mammals and fisheries** Éva E. Plagányi and Doug S. Butterworth
10:45	**Habitat transformation: The nature of loss and the loss of nature** Timothy J. Ragen
11:15	Break for Lunch
1:00	Issue discussions by each of four break-out groups
5:00	Adjourn for the day

6 August (Wednesday)

8:00	Plenary review of reports from discussion groups Presentation of Session C background papers
9:30	**The effects of long-term environmental change on marine mammals** Sue E. Moore
10:00	Break
10:15	**Deciding on units to conserve in the face of uncertainty** Barbara L. Taylor
10:45	**Adapting the management of marine mammals to cope with future change** Daniel Goodman
11:15	Break for Lunch
1:00	Issue discussions by each of four break-out groups
5:00	Adjourn for the day

7 August (Thursday)

8:00	Plenary review of reports from discussion groups
9:00	Plenary discussion of overlying themes Formation of “Future Directions” framework
11:30	Break for Lunch
1:00	Wrap-up discussion
3:00	Adjourn the meeting

Appendix E. Description of Proposed Marine Mammal Health Research Alliance

Prepared by Teri Rowles

Little is known about the ecological significance of disease in marine mammal populations since most research to date has focused on individual animal health. This dearth of information extends to the impacts of marine mammal disease on human health and the marine environment. A multidisciplinary approach is needed because many factors can affect the health of marine mammals and their environment, and because the interactions among these factors are complex. To be affordable and effective, a multidisciplinary program should be national in scale and should include all existing efforts and facilities.

Existing facilities address certain aspects of marine mammal health (e.g., studies of population biology, disease investigation, contaminants monitoring, development of new methods and diagnostics, and epidemiological modeling). However, minimal effort has been directed toward integration and coordination of the activities of these facilities. As a result, progress at understanding the health status of marine mammals, or living marine resources in general has been unacceptably slow.

A marine mammal health research alliance is proposed here to provide the needed coordination and integration. This alliance might be modeled after any of three cooperative efforts dealing with terrestrial wildlife issues in North America: The Southeastern Cooperative Wildlife Disease Study, encompassing 15 states, Puerto Rico, and federal partners; the Canadian Cooperative for Wildlife Health, a collaboration among Canada's four veterinary colleges and various wildlife management agencies; and the Center for Conservation Medicine, a consortium of federal, non-profit, and university affiliates.

The mission of the proposed alliance would be to coordinate a national program with a focus on marine mammal populations. It would integrate existing programs and establish new programs in subject areas that are not currently being addressed. The four main streams of inquiry would be general studies (marine mammal ecology, biology, population dynamics, physiology), field-based health studies (disease investigations, long-term health monitoring), development of methods and tools (sample diagnostics, method development, quality assurance, banking, research), and "informatics" (information management, epidemiology, risk assessment, modeling). The alliance also would provide emergency-response teams for intensive investigations of die-offs and epizootics. Medical techniques and tools that often are unavailable to field biologists would be made available through the alliance. The alliance also would provide a mechanism by which numerous data parameters regarding specific populations could be pooled for analyses. The "informatics" component would ensure that there are national databases to track diseases, contaminants, and harmful algal blooms and to manage population and environmental data in a comprehensive way. Several new positions would be created to support the alliance and fill gaps in expertise. Competitive research funding would be available for partners in states and territories, and graduate student training would be an integral part of the alliance's overall program.

The following groups are potential partners in such an alliance:

Major federal agencies – U.S. Geological Survey's National Wildlife Health Center and the National Oceanic and Atmospheric Administration (NOAA)

General studies – National Marine Mammal Laboratory, Florida Fish and Wildlife Conservation Commission, North Slope Borough, Marine Mammal Center, regional stranding networks, NOAA Honolulu laboratory

Field studies – North Carolina State University, Florida College of Veterinary Medicine, Marine Mammal Center, Mote Marine Laboratory

Methods, tools, and research – National Wildlife Health Center, Marine Mammal Health and Stranding Response Program, Hollings Marine Laboratory, Northwest Fisheries Science Center, Environment Canada

"Informatics" – University of California at Davis, Hollings Marine Laboratory, National Marine Mammal Laboratory, University of St. Andrews (United Kingdom)

Appendix F. Examples of Long-term, Ecosystem-scale Ocean Monitoring Progams

Prepared by David Checkley, Jr.

Following are some examples of programs that are or will soon be underway:

California Cooperative Fisheries Investigations (CalCOFI)

CalCOFI is a joint effort of the National Marine Fisheries Service, the California Department of Fish and Game, and the University of California, San Diego. The program was established in 1951 to study the ecosystem of the Pacific sardine and northern anchovy off California. The premise was, and remains, that fluctuations in populations of these small, pelagic fish could only be understood through ecosystem research. The result is a 52-year, continuing time series of standardized, hence comparable, measurements of ocean physics, chemistry, and biology. Marine mammal research has been included to a limited extent. The opportunity for a greater emphasis on marine mammals exists and is being pursued because:

- Sardines and anchovies are fished commercially but are also important prey of marine mammals;
- Marine mammal mortality from harmful algal blooms (e.g., domoic acid) appears to be increasing in this region;
- California's largest commercial fishery, in terms of biomass and monetary value, is the squid fishery, squid are important prey of marine mammals, and a 52-year time series of squid abundance indices is available through CalCOFI samples and data.

Pacific Coastal Observing System (PaCOS)

PaCOS is a coast-wide observing system for the California Current ecosystem. It is being developed by the National Marine Fisheries Service, together with west-coast universities, foundations, and conservation organizations. PaCOS will focus on federally managed species of fish, marine mammals, and turtles in an ecosystem and ocean climate context. A research plan and budget initiative for Fiscal Year

2006 are currently being developed. Marine mammal experts have been invited to participate in the planning process.

Other programs

The federal government has initiated planning and funded pilot projects for a U.S. ocean observing system. This long-term system will ultimately include all U.S. coastal waters and will consist of regional observing systems, such as the Gulf of Maine Ocean Observing System. While initial observation efforts have focused more on physical oceanography, the program provides opportunities for the incorporation of biological studies, including those on marine mammals.

A host of other entities exist, or are in the planning stages, that could provide additional opportunities for long-term observation of marine mammals and their ecosystems. These include areas protected to varying degrees from human activities (e.g., no-take areas, marine sanctuaries, and other types of marine protected areas); Long-Term Ecological Research programs; Ecological Studies of Harmful Algal Blooms; and other Federal, state, and local monitoring programs (e.g., near power generating plants). More regional monitoring programs have also been developed, such as the survey program to monitor manatee use of habitat around power plants in Florida. This study has been conducted for 26 years and includes the monitoring of associated environmental parameters.

These examples of large science programs share the common goal of observing the ocean over broad spatial and temporal scales. None (apart from the Florida manatee monitoring program just mentioned) has marine mammal research or monitoring as its primary focus, yet each affords opportunities for such work. Importantly, if marine mammal research were to be integral to those programs, they would provide long-term observations that are lacking, but needed, for ecosystem-based decision-making and management. Such programs are essential if we are to understand and prevent unacceptable adverse effects of human activities without unnecessarily constraining those activities.

Appendix G. Literature Cited

Laist, D. W., A. R. Knowlton, J. G. Mead, A. S. Collet, and M. Podesta. 2001. Collisions between ships and whales. Marine Mammal Science 17(1):35–75.

O'Hara, T. M., and T. J. O'Shea. 2001. Toxicology. Pp. 471–520 in L. A. Dierauf and F. M. D. Gulland (eds). Marine Mammal Medicine. Second Edition. CRC Press, Boca Raton, Florida (USA).

O'Shea, T. J., R. R. Reeves, and A. K. Long (eds). 1999. Marine mammals and persistent ocean contaminants: proceedings of the Marine Mammal Commission workshop, Keystone, Colorado, 12–15 October 1998. 150 pp. + vii.

Reijnders, P. J. H. 2003. Reproductive and developmental effects of environmental organochlorines on marine mammals. Pp. 55–66 in J. G. Vos, G. D. Bossart, M. Fournier, and T. J. O'Shea (eds). Toxicology of Marine Mammals. Taylor & Francis, London.