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

Assessment of the Cumulative Effects of Anthropogenic Stressors on Marine Mammals

National Research Council
Ocean Studies Board

Statement of Task

The National Research Council's Ocean Studies Board has previously convened four highly successful panels on the subject of biological effects of manmade underwater sound, which produced a progressive series of reports published in 1994, 2000, 2003, and 2005, with the latest report focusing on the potential for biologically significant effects on marine mammal populations. Sound, however, is only one of a variety of potential anthropogenic or natural stressors that marine mammals encounter, and it is often evaluated in isolation without consideration of the effects of other stressors (e. g. fishing, climate change, pollution, etc.), or consideration of how these other stressors may affect an animal's response to sound exposure. The committee will conduct a workshop and review the present scientific understanding of cumulative effects of anthropogenic stressors on marine mammals with a focus on anthropogenic sound. The committee will assess current methodologies used for evaluating cumulative effects and identify new approaches that could improve these assessments. The committee will examine theoretical and field methods used to assess the effect of anthropogenic stressors for:

- Short or infrequent exposure in the context of other known stressors (i.e. multiple stressors, both natural and anthropogenic); and
- Chronic exposure in the context of other known stressors;

The review of methodologies will begin by focusing on ways to quantify exposure-related changes in the behavior, health, or body condition of individual marine mammals and assess the potential to use quantitative indicators of health or body condition to estimate changes in vital rates and, in turn, estimate the potential population-level effects.

Technical Approach and Justification

Sound in the oceans is generated by a variety of natural and anthropogenic sources, and may affect marine life at multiple levels from behavioral disruption to population-level effects. Potential interactions between marine mammals and anthropogenic sound are of concern to the Navy, regulatory agencies, environmental community, and general public. Sound is only one of a variety of potential anthropogenic or natural stressors to which marine mammals are exposed. Other stressors may include pollutants, changes in prey availability and distribution, and displacement from preferred habitats. The biological significance of a behavioral response to sound is dependent upon the context of the exposure (i.e. feeding, diving, etc.), the status of the individual (i.e. age class, sex), condition of the animal (i.e. health status), and cumulative exposure to anthropogenic and natural stressors over various temporal and spatial scales.

Thus, it is challenging to attribute biological responses to only one of a suite of potential stressors. While the issue of effects of sound on marine mammals is a primary focus, the question of how to assess cumulative effects of human activities has broad ecological and conservation relevance. Environmental regulations require analysis of cumulative effects of human activities on wildlife populations, yet scientific methods to study this problem are limited thus far.

U.S. regulations under the National Environmental Policy Act define the cumulative impact of an action as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions" (40 C.F.R. 1508.7). Assessing these impacts on wildlife populations, therefore, must include an accounting of both cumulative effects that accumulate over time as well as those aggregate effects from multiple stressors that co-occur or overlap in time. The interactions among multiple stressors are potentially linear (additive) or non-linear (multiplicative, synergistic, exacerbating, or logarithmic). Sound exposure is one of multiple anthropogenic and natural stressors that wildlife populations encounter. However, it is often evaluated in isolation without consideration of the effects of other stressors (fishing, climate change, pollution, etc.), as well as if and how these stressors may affect an animal's response to sound exposure. There are currently few, if any, methods available to integrate the effects of many such responses on the ability of individuals to grow, survive and reproduce over a lifetime.

Analysis of the effects of noise on marine mammals, in the context of cumulative anthropogenic and natural stressors, is complicated by the fact that sound travels long distances in the ocean, so it can have effects far from the source. The impacts of exposure to discrete sound sources may involve relatively brief behavioral or physiological responses, making them difficult to observe. Furthermore, shipping and other human activities have led to a chronic elevation of ambient noise in the ocean. However, the effects of such increased ambient noise are not well understood, nor are effects of a discrete noise event superimposed on an elevated ambient noise background.

Metrics of animal health and/or body condition may provide one way to measure the integrated effects of multiple stressors in a given environment and provide a context in which to evaluate the specific effects of sound exposure on individuals. An improved understanding of cellular signaling pathways and proteostasis may offer insight into mechanisms for cumulative effects of multiple changes in health status. The commonality of metabolic pathways, often involving innate or adaptive immune responses, may explain how sub-lethal or mildly harmful factors can change an individual's health and thereby fitness (a combination of reproductive success and survival).

One promising approach is to link vital rates to behavioral and physiological changes by measuring body condition as a function of foraging success and energetics. If disruption of behavior or physiology results in reduced food intake or increased energy expenditure, this could affect body condition. In many species, the reproductive rate of females is limited by their energy stores, so variation in body condition can affect their reproductive rate and offspring survival. Changes in body condition can also affect survival via effects on the immune system and resistance to infectious agents. In this energy-based approach, body condition provides a state linking short-term and long-term effects on vital rates. A second potentially useful approach to quantifying cumulative effects is the development of methods to

evaluate common metabolic pathways that are altered by multiple factors, such as the metabolic response to oxidative stress.

The goal of the energy-based model approach is to derive a quantitative assessment of the stressor on a population measure such as growth rate; hence a quantitative framework is required to derive the linkages between: (1) the input disturbance and individual behavioral/physiological responses, (2) individual behavioral/physiological responses and changes in health/body condition, and (3) health/body condition and changes in demographic parameters and population outcomes. One option is to use individual-based stochastic simulation, basing simulation parameter distributions on values obtained from auxiliary analyses of relevant data, values obtained from the literature or expert opinion. A more coherent approach is to embed the stochastic model within a Bayesian state-space modeling framework, where all available data and expert opinion can be used jointly to estimate model parameters. The parameterized model can then be used to infer population consequences (and uncertainty) given a set of input scenarios. There has been much recent progress with both of these approaches.

A critical outcome of the proposed NRC study would be reviewing these various approaches (theoretical and field methods), as well as identifying potential new approaches, and developing specific recommendations on approaches to assess cumulative effects of multiple stressors on marine mammal populations that, in turn, have direct and indirect effects on vital rates and population health.

Subject Matter Expertise

Committee membership will be drawn from volunteers with expertise in environmental risk modeling; cumulative effects; ocean acoustics; marine bioacoustics; marine mammal ecology, behavior, and/or physiology; marine mammal health (e.g., toxicology); terrestrial and/or marine population biology; quantitative ecology; population consequences of disturbance; or other relevant fields.