# Population Consequences of Acoustic Disturbance of Marine Mammals

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## LONG-TERM GOALS

The long-term goal of this project is to improve understanding of how sound, or by extension any natural or anthropogenic disturbance, may affect probabilities of population viability or species persistence of marine mammals. Behavior of an animal (e.g., direction or rate of movement) may change in response to one or more disturbances. Changes in behavior may affect life functions such as feeding or breeding. Changes in life functions, in turn, affect vital rates such as recruitment or stage-specific survival. Vital rates affect probabilities of population viability or species persistence. Functional relations between vital rates and probabilities of persistence are well established, but functional relations between behavior and life functions, and especially between life functions and vital rates, remain challenging to quantify.

## OBJECTIVES

1. Explore how the U.S. National Research Council (NRC) committee's 2005 conceptual model of population-level effects of changes in behavior of marine mammals might be translated into quantitative models.
2. Consider how the NRC committee's conceptual model might be parameterized with existing or emerging data on the responses of large vertebrates to disturbance.
3. Define conceptual approaches for investigating transfer functions (e.g., time-energy budgets, trait-mediated responses).
4. Expand work by the NRC to include sensitivity analyses on transfer functions.
5. Outline exploratory models that might be used to model transfer functions, synthesize existing knowledge, examine potential mechanisms, or inform research and management.

## APPROACH

Work is conducted by a multidisciplinary research team of approximately 15 core participants with oversight from a steering committee [Dan Costa (University of California, Santa Cruz), Erica

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Fleishman, John Harwood (University of St. Andrews), Peter Tyack (Woods Hole Oceanographic Institution), and Mike Weise (Office of Naval Research)]. Additional participants are involved in some aspects of the work. The team meets in person approximately every 6 months (four meetings convened to date) to iteratively develop and interpret models and outline deliverables. Participants conduct the majority of analyses and writing at their home institutions between meetings.

Key participants are Jim Clark (Duke University), Dan Costa, John Harwood, Mark Hindell (University of Tasmania), Scott Kraus (New England Aquarium), David Lusseau (University of Aberdeen), Clive McMahon (Charles Darwin University), Dave Moretti (Naval Undersea Warfare Center), Leslie New (formerly University of St. Andrews, now Marine Mammal Commission), Rob Schick (Duke University), Lisa Schwarz (University of California, Santa Cruz), Sam Simmons (Marine Mammal Commission), Len Thomas (University of St. Andrews), and Peter Tyack.

## WORK COMPLETED

We have convened four meetings: from 28 September–1 October 2009 and 4–6 March 2010 in Santa Barbara, California, from 7–9 September 2010 in Woods Hole, Massachusetts, and from 10–12 April 2011 at the Atlantic Undersea Test and Evaluation Center (AUTEC). At the first meeting, the group developed a model for analyzing energy change during foraging trips by elephant seals (*Mirounga angustirostris* and *M. leonina*) and the effects of this energy change on pup survival. At the second, the group began to develop a model for coastal populations of bottlenose dolphins (*Tursiops* spp.). The third focused on how disturbance might affect northern right whales (*Eubalaena glacialis*). At the fourth meeting, the group developed a model for Blainville's beaked whales (*Mesoplodon densirostris*) on the AUTEC range.

### Elephant seals

New used a Kalman filter to fit models of the change over time in lipid reserves of foraging female southern elephant seals from Macquarie Island to data collected from satellite transmitters attached to these animals. New modeled the potential effects on lipid reserves of animals not feeding on a specified number of days during a foraging trip while traveling at the maximum observed rate. New used the relationship between maternal post-partum mass and pup survival reported by Arnbom et al. (1993) to investigate how the reduction in lipid reserves might affect the dynamics of the Macquarie Island population.

Schick analyzed the same telemetry data as New and additional data on northern elephant seals. He used Markov chain Monte Carlo methods to fit the data. He investigated three hypotheses of what might drive changes in lipid reserves during a foraging trip: interactions between the organism and its environment, the animal's initial lipid:lean mass ratio, and, for southern elephant seals, the foraging strategy (e.g., pelagic, in the Ross Sea [mostly], or on the continental shelf). Schick examined the effect on lipid reserves of environmental covariates, including estimates of zooplankton density at different water depths (for northern elephant seals) and distance to the ice edge (for southern elephant seals).

Schwarz used a Bayesian version of a Cormack-Jolly-Seber model that accounted for tag loss to examine the response of pup survival to mass at weaning, sex, year, and environmental events (the Antarctic oscillation and the El Niño – Southern Oscillation). Tagging effort for northern elephant seals extended over many years, but with relatively small tagging effort each year, whereas southern elephant seals were tagged intensively in a few years.

**Coastal populations of bottlenose dolphins**

New originally developed a model to mimic observations of the resident population of bottlenose dolphins in Doubtful Sound, New Zealand. She recently extended the model to describe the observed behavior of dolphins in the Moray Firth, Scotland. Four states (energetic status and three motivational states: hunger, fear, and need to socialize) are modeled for each coastal bottlenose dolphin. The values of these states determine the most likely activity of an individual in a particular time step. The overall activity of the school (traveling, feeding, resting, or socializing) is determined by the mean motivational levels of individuals. The activity of the school affects the values of the states of all its individuals in the next time step, when the activity of the school is likely to change if more than 50% of the individuals are dissatisfied with the school's current activity.

**Northern right whales**

Data held by the Northern Right Whale Consortium include more than 30 years of visual and photo-identification surveys as well as records of all documented births and deaths in the northern right whale population. The health of each individual and its degree of scarring (usually the result of vessel collision or entanglement in fishing gear and mooring lines) is assessed visually every time the animal is photographed. Eighty-two percent of photographed animals have been entangled in some way. The current population size is estimated to be around 475, and genetic variation of 350 individuals has been assessed at 35 microsatellite loci. There are smaller sets of data on contaminant and fatty acid composition from blubber samples and on hormone levels (corticosteroids, sex, and thyroid) from fecal samples. In addition, there are data on the abundance and caloric density of prey in the Gulf of Maine and the Great South Channel.

Members of the Consortium and a subset of the working group met in Boston, Massachusetts in June 2011. The proposed to incorporate data on entanglement and health into a model of population growth developed by Schick and Jim Clark. The model will explore the effects of disturbance on individuals and the population. The health assessment will provide a foundation for assessing the effects of diverse disturbances, including acoustic disturbance, on right whales.

**Beaked whales**

The working group agreed to develop a model of *Mesoplodon densirostris* on the AUTEC range that builds on analysis by Hooker et al. (2002) of the potential energetic costs of disturbance to northern bottlenose whales. This model requires estimates of the extra daily energy costs of fetal development and lactation for mature female *M. densirostris* and the likely net energy gain from each foraging dive. This information could be used to estimate the energetic effects of a given decrease in the number of foraging dives, which might result from disturbance. The effects of this decrease would depend on the life history of individual adult females. The energetic costs of pregnancy are relatively small, and it seems unlikely that females would abort a fetus in response to a short-term decrease in energy intake. However, the decrease in energy intake might result in a reduction in the growth rate of the fetus. If a female's energy reserves can compensate for lost energy intake, the inter-calf interval likely would increase because a female is assumed to require more time to replace lost reserves after a calf is weaned.

Alternatively, females could reduce the supply of milk to their calves during periods of low energy intake. Reducing the supply of milk could result in an increased inter-calf interval if calves are weaned at a fixed body size, or a potential reduction in calf survival if they are weaned at a fixed age. These assumptions suggest that some demographic rates (particularly inter-calf interval) will differ between

AUTEC and Abaco. These differences in demographic rates will lead to differences in age and size structure between the populations.

During the reporting period, project work was presented during symposia at meetings of the Association for Environmental Studies and Sciences (June 2011, Burlington, Vermont) and Ecological Society of America (August 2011, Austin, Texas) and at a conference on Effects of Sound in the Ocean on Marine Mammals (September 2011, Amsterdam, The Netherlands). We scheduled a symposium in Washington, D.C., jointly hosted by Office of Naval Research and the Marine Mammal Commission, which will be held in October 2011.

## RESULTS

Models suggest exclusion of southern elephant seals from foraging habitat can affect body condition, pup survival, and population growth rate. Adult female elephant seals build lipid reserves while foraging at sea and use these reserves to feed their pups during the brief breeding season. The size of a female's pup at weaning is positively correlated with its subsequent survival, and is dependent on its mother's lipid mass when she returns to land. If breeding females are excluded from foraging habitat for more than 47 days within a year, no pups would be born in that year. Fecundity estimates from previous work combined with Schwarz's estimates of survival rate of southern elephant seals suggest the growth rate of the Macquarie Island population is stationary, which coincides with the lack of observed changes in abundance since the mid-1990s.

Southern elephant seals were leaner than northern elephant seals, but were considerably larger. The leanest southern elephant seals gained lipid more rapidly than those in the other classes. Southern elephant seals that foraged in the pelagic zone showed higher rates of lipid loss during the initial and final phases of a foraging trip than those that foraged on the continental shelf, but higher rates of lipid gain during the intermediate phase. Similar differences were observed between all southern elephant seals and northern elephant seals.

Some physiognomic features, such as saddle size, might provide a quantitative index of energetic status of bottlenose dolphins. The best information on energetic status is likely to come from studies of bottlenose dolphins in Sarasota Bay, Florida, where longitudinal data are available on individual animals that have been captured repeatedly over decades.

Much of the observational data on the behavior of bottlenose dolphins comes from focal follows of entire schools, such as those made in Doubtful Sound and the Moray Firth. Such studies assume that all the individuals in a school can be categorized as performing the same behavior at a particular sampling instant. However, many working group members felt this assumption was unrealistic. Data from Sarasota Bay might be helpful for clarifying the actual degree of synchrony in behavior among school members.

## IMPACT/APPLICATIONS

Multiple sectors (e.g., regulatory agencies, industry, non-governmental organizations, and researchers motivated by curiosity or applications) wish to understand whether observed changes in behavior may relate to changes in probabilities of persistence. Native subsistence hunters also wish to understand whether short-term changes in behavior may affect long-term spatial distributions of animals. The concept that behavioral responses to disturbance are not surrogates for population-level responses to disturbance is widely understood. However, without tractable methods for quantifying population-level effects, most sectors will be restricted to estimating exposure of individual animals to disturbances (e.g., sound exposures), changes in habitat quantity or quality (e.g., changes in communication space or access to foraging habitat), and behavioral responses of individual animals.

Improved understanding of transfer functions, whether theoretical or empirical, might help to guide research and management, and to project how marine mammals will respond to alternative scenarios of anthropogenic sound. Inferences also are directly relevant to assessing the potential effects on marine systems of climate change, changes in human density, and coastal development.

We anticipate that deliverables and inferences from the team's work, and direct communication with potential end-users, will inform national and international legislation and scientific guidance on conservation status of marine mammals. Examples of these applications include the Endangered Species Act and the Marine Mammal Protection Act in the United States, the IUCN Red List categories and criteria, and the Species and Habitats Directive in the European Union.

## RELATED PROJECTS

Fleishman is leading a project on cumulative effects of underwater anthropogenic sound on marine mammals for BP Exploration. There is some overlap in participants between the groups, and open communication to maximize complementarity. To date, the cumulative-effects project has focused on effects at the individual level. The ONR-sponsored project may provide a means for evaluating how effects might transfer to the population level.

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