POPULATION CONSEQUENCES OF ACOUSTIC DISTURBANCE FACT SHEET

E&P **SOUND & MARINE LIFE** PROGRAMME

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PCAD FACT SHEET

Toward a Better Understanding of the Population Consequences of Sound on Marine Mammals

The majority of research on how sound in the ocean affects marine mammals has focused on short-term behavioural responses[1]. However, there is a general lack of knowledge about the potential long-term impacts of human-made sound on the health and well-being of the marine mammal population. Specifically, how do individual behavioural responses relate to long-term population health?

To address this question, the National Research Council (NRC) of the United States National Academy of Sciences convened and developed a framework known as the Population Consequences of Acoustic Disturbance (PCAD) model. Published in 2005, this model was devised to help researchers begin to understand the links between behaviour, life functions, and ultimately, survival of a population. (See Figure 1. The PCAD Framework.) These links, or transfer functions, describe the relationships among the different types of response variables. Some transfer functions, such as how an animal's behaviour can change when exposed to sound, were well-understood and well-studied. Other transfer functions had not been developed.

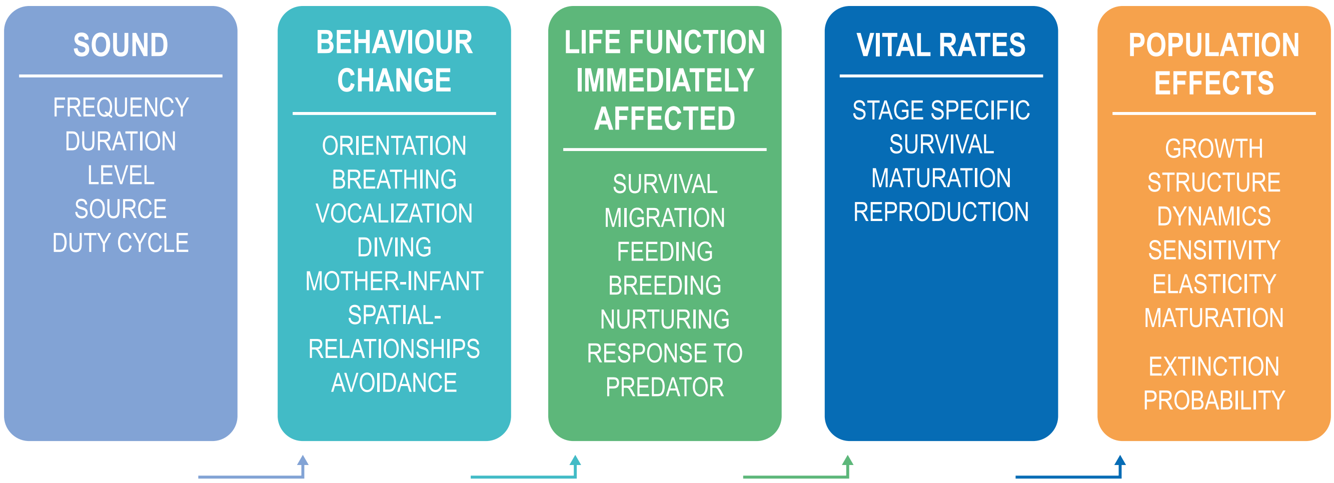

Figure 1. The PCAD Framework

1 Southall, B. L. 2012. Noise and Marine Life: Progress From Nyborg to Cork in Science and Technology to Inform Decision Making. Pages 3-9 in A. N. Popper and A. Hawkins, editors. Effects of Noise on Aquatic Life.

In 2009, the United States Navy's Office of Naval Research (ONR) set up a working group to quantify the poorly-understood transfer functions using real-world data from four case studies (elephant seals, bottlenose dolphins, North Atlantic right whales and beaked whales), of which the Joint Industry Programme (JIP) co-funded the work on these first two species. The case studies span several marine mammal taxonomic groups and reproductive strategies, and involve both data-rich and data-poor populations. Through the process of developing the transfer functions, the group restructured the original PCAD model to clarify the linkages between behaviour and physiology and their multiple access points to acute and chronic effects. Further, they realized that the PCAD model was broadly applicable to all forms of disturbance not just acoustic.

Therefore, the working group published a revised model, known as the Population Consequences of Disturbance (PCoD). (See Figure 2. The PCoD Model.)

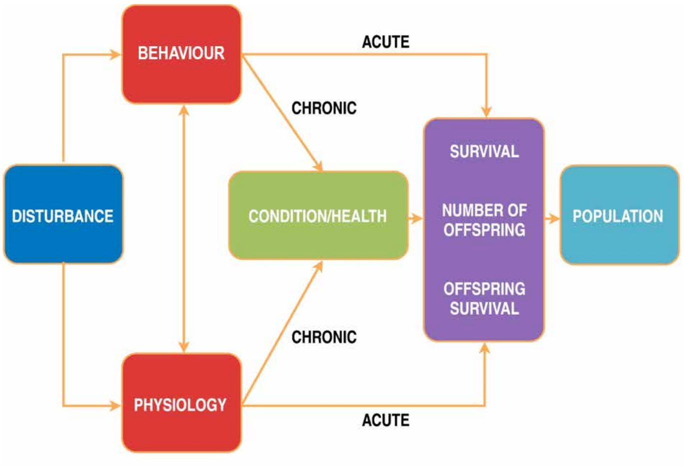

Figure 2. The PCoD Model[2]

This model addresses any type of disturbance, such as shipping traffic or climate-related disturbances, and is applicable to both marine and terrestrial animals. Longer-term impacts are measured by changes in the animals' health, which may eventually affect reproductive success and survival, which in turn may affect population status and trends. Again, the transfer functions between behaviour/physiology, health, and vital rates were the least developed, while the transfer functions between vital rates and population status and trends are more advanced.

Using the PCoD Model

There are a variety of approaches that could be used to detect a behavioural response that is meaningful at a population level. One of the most promising, and the focus of much of the JIP-funded ongoing research, is a bioenergetics model, in which the costs associated with disturbance are linked to reductions in foraging success.[2,3]

Energetic models provide a means to quantitatively assess the energy that animals spend feeding and how they allocate those resources. Energy flow can be described as what goes into an animal as food, and what comes out in the form of growth, reproduction, repair, waste and metabolic work. By knowing the energetic needs of an animal, we then can understand the point at which lost foraging will have a negative effect on population growth. If animals consume an adequate amount of food, they thrive and reproduce normally: the population will grow. As prey become less available, or the animals' ability to forage is reduced, the animals must use more energy to acquire the same amount of food, or they have a net loss of energy intake. This may eventually affect the health/body condition, and thus reproduction or survival, and may have long-term consequences for the population.

The ability to determine the amount of energy lost due to exposure to a sound or other disturbance is therefore an important step to creating a predictive model. Worst-case scenarios have assumed that foraging declines to zero when animals are exposed to a sound source, and the animals do not have a way to compensate for the lost energy intake[3]. Stochastic Dynamic Program models (SDP models) determine how animals might compensate for lost foraging through behavioural decisions that will still maximize reproduction and survival[4]. (See "Ongoing Studies" below.)

[2] New, L.F. et al. (2014) Using short-term measures of behavior to estimate long-term fitness of southern elephant seals. *Marine Ecology Progress Series*, 496:99-108. https://doi.org/10.3354/meps10547.

[3] Costa, D.P. et al. (2016) A Bioenergetics Approach to Understanding the Population Consequences of Disturbance: Elephant Seals as a Model System. In: Popper A., Hawkins, A. (eds) *The Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology*, vol 875. Springer, New York, NY.

[4] Mchuron, E.A. et al. (2017) State-dependent behavioral theory for assessing the fitness consequences of anthropogenic disturbance on capital and income breeders. *Methods in Ecology and Evolution*, 8:552-560.

JIP-funded research has focused on determining the energetic needs of various species for which there is a large historical dataset. (See "Elephant Seals & Sea Lions" and "Ongoing Studies" below.) These results, which span a range of reproductive and foraging strategies, can be used as proxies for similar species with less data.

Top Down or Bottom Up

When short-term responses are not known or are difficult to quantify, the level of disturbance used in the model can range from a conservative worst-case scenario, to more realistic levels. For these reasons, PCoD is a very promising risk assessment tool for industry as well as government and academia.

There are two basic approaches to utilizing and interpreting the PCoD model. In the "top down" approach, researchers start at the population level, then look at reproductive rates, mortality rates and health status, and figure out how much loss of energy it would take to make the population decline over time. However, this approach does not address how the energy was lost (which may occur in a variety of ways) or how animals may adjust behavior to minimize lost energy.

The "bottom up" approach involves adding a disturbance as input and predicting how it will affect a population through influencing the behaviour and physiology. While this would be valuable information to have, there are very few data available as yet to support this approach.

While there are very little data available for some species to support this approach, the case studies may become valuable inputs to determine general patterns for different reproductive strategies, foraging strategies, migratory patterns, and population sizes.

Objectives of the JIP PCoD-related Research

The JIP's research in this area has a set of short-term and long-term objectives. In the short term, the JIP is working to:

- Develop tools and strategies to evaluate risk (determine the consequences and likelihood of behavioural responses occurring)
- Develop bioenergetics models for different functional groups using data on similar species

In the long term, the JIP intends to:

- Develop screening tools to distinguish higher-risk scenarios from lower-risk scenarios to focus further efforts
- Develop tools for applying PCoD to risk assessments

Studies Conducted by the JIP

Literature Review

One of the JIP's initial multi-year efforts was a comprehensive literature review[5] on the state of the art in population modeling. Released in 2009, this report summarized dozens of studies regarding population dynamics in a wide variety of marine and terrestrial animals, and covered myriad factors affecting a population's rate of increase. Among other things, it included a study from the NRC that quantified what a behavioural response is, and how it might result in a change in life function. The NRC-characterized behavioural responses include changes to diving, breathing and resting behaviour, changes in swimming speed, vocalization, changes in direction of travel, and the relative location of mothers to their offspring. These last two responses have the most potential to disrupt nurturing behaviour, feeding, and other physiological factors.

[5] Available at http://gisserver.intertek.com/JIP/dmsJIP.php

Elephant Seals & Sea Lions

The first PCoD working group case study that led to the development of the PCoD model utilized a bioenergetics approach and applied it to southern elephant seals[2]. The JIP sponsored component of this effort examined the response of northern elephant seals and was headed by Dr. Daniel Costa of the University of California Santa Cruz (UCSC)[3]. The maternal condition of these animals can be measured directly as mass or lipid (fat) content, providing an accurate empirical measurement and a foundation for this analytical framework[6,7]. Furthermore, changes in buoyancy over an elephant seal's foraging trip can be used to estimate the daily lipid mass gain while at sea. The scientists used lipid mass gain during a foraging trip as the energetic metric linked to reproduction, pup wean mass, and pup survival[8]. Using a large simulated disturbance with a diametre of 100 kilometres (about 62 miles), they found that most animals spent little-to-no time in the disturbance zone, resulting in undetectable changes in pup survival.

Using tracking data, the researchers estimated the potential for California sea lions to be exposed to an acoustic disturbance. Because this species has a much more limited foraging range, individuals were more likely to be exposed to a disturbance of even a smaller radius of 25 kilometres (about 15 miles). However, sufficient data on the energetic component that would link lost foraging time with offspring health and survival were not yet available.

Ongoing Studies

In 2013, Dr. Costa and his team at UCSC were contracted by the JIP to further advance the bioenergetic models for a range of functional species groups. In particular, this JIP-sponsored research is gathering data and creating bioenergetics models for bottlenose dolphins, humpback whales, and blue whales, and continuing research on California sea lions and elephant seals.

Using data gathered through tagging and techniques to measure metabolic rates, the intent of the JIP's current research is to develop models of changes in foraging behaviour in response to disturbance for the above species. This effort includes calculating the energy required for successful survival, pregnancy, and nursing, developing SDP models for specific populations, and investigating how a species' range will influence its probability of exposure to a sound source. Species-specific curves are developed showing the relationship between loss in energy intake and the impact on vital rates for that species.

So far, this project has resulted in peer-reviewed publications on SDP modeling[4], California sea lion bioenergetics[9], blue whale SDP model and bioenergetics[10], western gray whale bioenergetics[11,12], and elephant seal bioenergetics at sea[13]. Additional manuscripts are being prepared on exposure probability, humpback whale bioenergetics, a California sea lion SDP model, and a full elephant seal bioenergetics model.

6 Schwarz, L.K. et al. (2015) Comparisons and Uncertainty in Fat and Adipose Tissue Estimation Techniques: The Northern Elephant Seal as a Case Study. PLoS ONE 10(6): e0131877. https://doi.org/10.1371/journal.pone.0131877.

7 Villegas-Amtmann, S., B. I. McDonald, D. Páez-Rosas, D. Aurioles-Gamboa, and D. P. Costa. 2017. Adapted to change: Low energy requirements in a low and unpredictable productivity environment, the case of the Galapagos sea lion. Deep Sea Research Part II: Topical Studies in Oceanography 140:94-104.

8 Schwarz, L.K. et al. (2015) Comparisons and Uncertainty in Fat and Adipose Tissue Estimation Techniques: The Northern Elephant Seal as a Case Study. PLoS ONE 10(6): e0131877. https://doi.org/10.1371/journal.pone.0131877.

9 Mchuron, E.A. et al. (2017) Energy and prey requirements of California sea lions under variable environmental conditions. *Marine Ecology Progress* Series, 567:235-247.

10 Pirotta, E. et al. (accepted) A dynamic state model of migratory behavior and physiology to assess the consequences of environmental changes and anthropogenic disturbance on marine vertebrates. *American Naturalist*.

11 Villegas-Amtmann, S., L. K. Schwarz, J. L. Sumich, and D. P. Costa. 2015. A bioenergetics model to evaluate demographic consequences of disturbance in marine mammals applied to gray whales. Ecosphere 6:art183.

12 Villegas-Amtmann, S. et al. (2017) East or west: the energetic cost of being a gray whale and the consequence of losing energy to disturbance. *Endangered Species Research*, Vol. 34: 167–183. https://doi.org/10.3354/esr00843.

13 Maresh, J.L. et al. (2015) Summing the strokes: energy economy in northern elephant seals during large-scale foraging migrations. *Movement Ecology*, 3, 1-16.

ABOUT THE JIP

One of the most extensive environmental industry research programmes bringing together the world's foremost experts across industry, academia and independent research centres.

This fact sheet has been produced by the IOGP E&P Sound and Marine Life Joint Industry Programme (JIP). The JIP was founded in 2005 and supports research to help increase understanding of the potential effect of sound generated by oil and gas exploration and production activity on marine life.

To learn more about the JIP and our research, please visit www.soundandmarinelife.org

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