BIAS IN ESTIMATES OF NUMBERS OF MARINE MAMMALS AFFECTED BY UNDERWATER NOISE

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1. INTRODUCTION

Wade *et al.* (2010) addressed the question of whether scientists' funding sources were correlated with their choice of existing data to consider on how marine mammals are affected by noise. In this paper, I examine whether even straightforward application of existing data is likely to lead to biased conclusions.

The data on effects of noise on marine mammals are limited. As a result, models have been developed to extrapolate existing data to novel contexts. These models include methods for estimating sound propagation efficiency, individual variation in responsiveness within species, inter-specific variation in responsiveness, and factors that can be ignored by the model. Like all empirical data, data on marine mammal responsiveness contain uncertainties due to limited sample sizes and resulting broad confidence intervals. Measurements on the physical sources themselves may include uncertainty due to limitations of measurement equipment. While the data themselves are typically reported as unbiased best estimates within confidence intervals, bias may be generated when best estimates are used in the models without consideration of their uncertainty.

2. METHODS

Published literature, environmental impact statements, and permit applications were reviewed to identify assumptions that could lead to biased conclusions.

3. RESULTS

3.1 Bias from physical measurements

Equipment for making physical measurements of sound is optimized for measurements within a limited range of frequencies and amplitudes. E.g., airguns have been reported to be loud, low-frequency noise sources. The early measurements of these devices were thus made with equipment optimized for loud, low-frequency sound. Reports of the physical properties of these devices reported their low-frequency content, but did not report the level of high-frequency content, as the equipment was not calibrated to measure those frequencies. Consequently, modelers have assumed only low frequency energy is present in airguns.

However, Bain and Williams (in review) found airguns also contain biologically significant levels of high frequency energy. That is, application of the early measurements is biased against predicting effects on high frequency-hearing specialists. As a result, effects on these species tend to be underestimated.

Sound propagation models are also based on physical measurements. The measurements produce a distribution of received levels at various distances from the source, and the mean and confidence intervals can be calculated. In turn, the radius at which effects are likely to cease to be biologically significant is calculated. Then, the area in which effects are likely to occur is calculated, and multiplied by density to estimate the number of individuals likely to be affected.

However, use of the best estimate of the radius does not lead to the best estimate of area when there is uncertainty. This is because received levels tend to decrease with the log of distance and area is proportional to the square of the radius to the threshold. When the radius to the threshold contour is at the upper confidence level, the affected area increases more than it decreases when the radius to the lower confidence level is determined. Note that the bias toward underestimating the affected area increases with increasing uncertainty.

3.2 Bias from biological measurements

As pointed out above, uncertainty increases bias, and individual variation is a source of uncertainty. The US Navy has employed a risk continuum (or "dose-response") function based on the level at which the most sensitive individuals begin to be affected and the level at which 50% of individuals are affected to account for individual variation. However, the parameters plugged into this model can be sources of bias when indices rather than actual values are employed. In field studies, the lower threshold would only be available as an anecdote, and as Wade et al. (2010) pointed out, anecdotes are difficult to publish. The best available approximation is commonly the level at which a statistically significant result is detectable. This, of course, depends on the sample size of the study, which is typically kept small by mitigation protocols. The larger the sample, the less biased a model substituting the significance threshold for the actual minimum would be. The uncertainty in the 50% level will also depend on sample size, and, as mentioned above, uncertainty contributes to bias. A serious methodological source of bias sometimes employed is to use the 50% level for one kind of effect as the minimum level and another type of effect for the 50% level in the model.

Sociality may make the risk model irrelevant. That is, group cohesion depends on all animals in the group responding in the same way to a given level of noise, and may increase the number of individuals affected.

Another source of bias is field studies that are based on the individuals nearest to the noise source. That is, many studies are structured with observers based on the vessel towing the noise source, and thus observations are limited to individuals close to the source. Individuals which move away from and remain too distant from the source to be observed are not included in the study. Therefore, the individuals included in the study are the subset of the population most tolerant of close approaches or least able to avoid the source.

The data of Calambokidis *et al.* (1998) are illustrative of this point. They observed marine mammal behavior from the vessel towing an airgun array; a small vessel that operated at variable distances from the airguns, including distances in excess of 70 km; and aerial platforms. Observations of porpoises near the source vessel consisted primarily of Dall's porpoises. In contrast, observations from the platforms distant from the airguns consisted primarily of harbor porpoises. That is, a larger portion of the harbor porpoise population avoided the airguns at a distance where they could not be observed by the mitigation team than did Dall's porpoises. Conclusions based only on the porpoises near the array would only reflect the responses of a small fraction of harbor porpoises in the study area, and hence be biased. Similarly, bowhead whales have been sighted near noise sources by vessel-based observers, while aerial surveys reveal deflections at long range (LGL *et al.* 1999).

Data from experiments with captive marine mammals are fundamental to many predictions of effects on wild marine mammals. However, there is inter-specific variability in the ability of cetaceans to survive in captivity (Bain 1988, DeMaster and Drevenak 1988). The bulk of data on audition in cetaceans comes from the small number of species that survive relatively well in captivity. To the degree survivorship is correlated to ability to tolerate noise from pumps and filters, there is potential for bias in the availability of data toward noise tolerant species. The exception is harbor porpoises, in which beach-stranded individuals have been extensively studied, but they may prove the rule by being relatively noise-intolerant (Bain and Williams in review).

Inter-specific variation is another source of uncertainty. Attempts to address this have been made by assuming that species with similar anatomy would have similar vulnerability to noise (Southall *et al.* 2007). However, Bain and William (in review) found this was not the case. They found harbor porpoises (*Phocoena phocoena)* were significantly more affected by airguns than the closely related Dall's porpoise (*Phocoenoides dalli*). Similarly, Steller sea lions (*Eumetopias jubatus*) tended to be more strongly affected by noise than California sea lions (*Zalophus californianus*). Stone and Tasker (2006) found similar differences between *Lagenorhynchus* species in the Atlantic.

4. DISCUSSION

These sources of bias have important implications for many issues within the marine mammals and noise arena. Mitigation and monitoring need to be planned over much greater distances than is commonly done currently. Additional habitat-specific risks may need to be addressed in more distant areas. Estimation of cumulative effects will require consideration of longer exposures, more repeated exposures, and more individuals affected overall. New data needed for more accurate estimates of the effects of noise on marine mammals are primarily the level at which 50% of individuals respond to noise in a wide variety of species.

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