Title	Developing an auditory weighting function for low-frequency whales
Administered by	Headquarters
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Procurement Type(s)	Inter-agency
Approx. Cost	$600 total (in thousands); 200k/year over three years
Performance Period	FY 2019–2022
Date Revised	April 9, 2018
PICOC Summary	
Problem	It is not possible to conduct a hearing test on a large baleen whale, yet we are required to know this information for analyses under the Marine Mammal Protection Act (MMPA) and Endangered Species Act.(ESA) . Therefore, the hearing abilities of low-frequency (LF) whales remains one of the major "unknowns" as the regulatory community has tried to deal with effects of noise on marine mammals. The result is potential over-estimation of takes and/or effects and improper application of mitigation.
Intervention	There are multiple scientific approaches to answer the question (see below). Although this question has existed for some time, this is the right place and right time to pursue this project, mainly due to partnership interest and advances in research methodologies. The SOST interagency task force for ocean noise and marine life (comprised of approximately 8 agencies) recently identified this question as the #1 information need on marine sound issues for broad-scale interagency support. Agency members of this task force have committed to contributing funds to partner on this project.
Comparison	There is no way to obtain a behavioral audiogram or electrophysiological audiogram from a free-swimming baleen whale. Instead, we can examine the physiology of the auditory system from whale carcasses and, using finite-element modeling, generate a digital model. Then that digital model can be subjected to sound waves to determine how the auditory system would respond - i.e., how the whale would "hear" if it was alive. This is the currently the best conceivable method for addressing this question. The other approach is to obtain AEP measurements from stranded animals. In this case, neurological responses to played-back sounds would be measured. If this project is not implemented, the best estimates for baleen whale hearing will continue to come from proxy species (e.g., odontocetes), but the accuracy of these proxies is also unknown.
Outcome	Results from either of these methods would be compared to the existing low-frequency hearing function used in the 2016 NMFS acoustic criteria and would serve to improve the criteria. This criteria, in turn, forms the foundation of all analyses under the MMPA and ESA. For all other hearing groups *except* LF whales, these criteria are based off of real data. The lack of meaningful, validated data for LF whales has made it extremely challenging for NMFS and others to derive meaningful regulatory "not-to-be-exceeded thresholds" for noise sources, as required under the MMPA and ESA.

	The results of this study will be used to inform future versions of the NMFS acoustic criteria and be more immediately used in BOEM marine sound analyses. Further, this project contains the validation of hearing models - models which were previously rejected by NMFS due to lack of validation. It also will advance the technology for obtaining new data from stranded whales. Accurate hearing data will allow for more accurate "take" estimates under the MMPA and ESA or BOEM-authorized activities such as G&G surveys and pile-driving. At the moment the models are likely to be overly conservative due to the lack of data and potentially result in overestimates of effects and over-application of mitigation.
Context	Depends on the method chosen. The data need is national. Information on hearing abilities from just one species of baleen whale will significantly advance the current understanding (which is almost nonexistent), so the results from one species would be extrapolated to other species.

BOEM Information Need(s): Understanding the auditory capabilities of LF whales is the biggest remaining knowledge gap in the field of marine bioacoustics as well as regulatory analyses under the MMPA and ESA. Specifically, BOEM needs to know the shape of the audiogram, as well as the lowest-amplitude sound that LF whales can detect, in order to build auditory weighting functions. These weighting functions are built into the "acoustic criteria" that NMFS requires for estimating "takes" from acoustic exposure. Therefore, this information is imperative for BOEM to assess the potential effects of its noise-producing actions (from both oil and gas and renewable energy) on these species, many of which are highly threatened, are afforded additional legal protection and are the focus of stakeholder concerns. Faced with the lack of information that we have now, regulators are forced to use information from proxy species (captive odontocetes) as stand-ins, but given the differences in life-histories, hunting strategies, and communication signals between baleen and toothed whales, these proxies are likely inadequate.

Background: Due to a lack of knowledge about their hearing capabilities, the NMFS 2016 Acoustic Criteria used conservative assumptions in establishing the auditory weighting function for low-frequency whales, especially for the lowest frequencies (<1 kHz). This resulted in relatively low numerical thresholds for several source types, such as low frequency impulsive sources (i.e. airguns). Low thresholds result in increased take estimates – a larger number of animals that would experience temporary or permanent threshold shift. This in turn leads to overly conservation analyses of effects and additional requirements for mitigation, the effectiveness of which is also poorly understood.

It is worth noting that BOEM has funded field work (e.g., the BRAHSS study ($2.2 mil), SWSS study ($9 mil),) which looked at the behavioral response of certain cetacean species to man-made sounds. At-sea Controlled Exposure Experiments are inevitably high-cost, but due to high individual variability and the difficulty of obtaining large sample sizes for such highly-migratory species, these studies have yielded mixed results. The return-on-investment for these field studies has been relatively low. The methods proposed here are not field-based behavioral work, but instead rely on physiological or

modeling methods (which need to be validated). As such, their potential return on investment (especially when comparing costs between methodologies), is much higher.

The time is right for this project because:

- This has been a need for the last several decades, but there is more focused attention on this issue since the publication of the NMFS acoustic criteria in summer 2016.
- BOEM has surveyed federal agencies via the SOST Ocean Noise and Marine Life task force to rank over 100 remaining "knowledge gaps" related to ocean noise. This topic emerged as the #1 knowledge gap across agencies. It also ranked at the top within a group of 13 BOEM SMEs that were also surveyed.
- The SOST group plans to put forth this topic in the next LMR Broad Agency Agreement (summer 2018) in order to solicit proposals.
- Within the Navy, ONR and LMR are ready to commit about $250,000/year over three years, with MMC, NSF, and NOAA able to contribute smaller amounts (in the 10s of thousands).
- One of our federal colleagues already has a permit in-hand for accessing stranded animals for hearing tests. This was previously a big logistical hurdle and would be very helpful in the later stages of this project.
- It is also worth mentioning that the US Navy and others have previously funded projects that used finite element modeling (FEM) of the head and inner ear of some LF species. Because this work has not been fully validated (although it could be, pending implementation of this study), NMFS did not incorporate this data into the 2016 acoustic criteria. Additionally, there has been recent progress in electrophysiological (AEP) techniques that measure the neural response of stranded whales, but these tools require further development.

Objectives: To build an audiogram for low-frequency cetacean(s).

Methods: The SOST group has decided to put forth a BAA that would include three research areas:

1. Validation of finite-element model outputs of whale skulls - may include:
    a. Validation of the bone conduction pathway
    b. Scanning an additional baleen whale species—e.g., a Bowhead that is obtained from subsistence harvest, or a stranded animal that can be mobilized quickly before decomposing.
2. Improve equipment and methodology for AEP methods

a. Development of appropriate transducer - a portable speaker that can reproduce sounds <1 kHz - this remains a major technological hurdle.
b. Testing of appropriate size and placement of subcutaneous needles – this can be started with sounds above 1 kHz, before the appropriate transducer has been developed.
c. Note: later stages of AEP work would include testing on real, stranded animals, but the steps above are necessary first.

3. Open-ended call for proposals that aim to build an auditory weighting function for LF whales - using new ideas, methods, or technology

Specific Research Question(s):
What is the shape of the audiogram for LF whales?

References:

Cranford, T. W. and P. Krysl (2015). "Fin whale sound reception mechanisms: skull vibration enables low-frequency hearing." PLoS One 10(1): e0116222.

Cranford, T. W., P. Krysl and M. Amundin (2010). "A new acoustic portal into the odontocete ear and vibrational analysis of the tympanoperiotic complex." PLoS One 5(8): e11927.

National Marine Fisheries Service. 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (NOAA technical memorandum NMFS-OPR-55)

Johnson, A. C. (April 2018). Scientists use rocket scanner to learn how whales hear: first whole-body CT scan of a minke whale yields insights on whale communication. This is a recent article about forthcoming work from Cranford and colleagues (not published yet, but will be presented at an upcoming conference).