

STUDY TITLE: Optimization of Towed Passive Acoustic Monitoring (PAM) Array Design and Performance Study

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OCS STUDY NUMBER: BOEM 2021-086

NUMBER OF PAGES: 32

CONTRACT NUMBER(S): 140M0119F0051

SPONSORING OCS REGION: Headquarters

APPLICABLE PLANNING AREA(S): North Atlantic, Mid Atlantic, South Atlantic

FISCAL YEAR(S) OF PROJECT FUNDING: 2020, 2021

COSTS BY FISCAL YEAR: 2020: \$29,775; 2021: \$168,725

CUMULATIVE PROJECT COSTS: \$198,500

COMPLETION DATE OF REPORT: 18 February 2021

PROJECT MANAGER(S): Melanie Cahill

AFFILIATION (OF PROJECT MANAGER): CSA Ocean Sciences Inc.

ADDRESS: 8502 SW Kansas Ave, Stuart, Florida 34997

PRINCIPAL INVESTIGATOR(S): Aaron Thode¹; Shima Abadi²; Mary Jo Barkaszi;

KEY WORDS: Passive Acoustic Monitoring; mitigation; numerical model; algorithm; offshore renewable energy

BRIEF ABSTRACT:

A numerical model for simulating the localization performance of a three- or four-hydrophone towed passive acoustic monitoring (PAM) array on multiple species clusters has been developed that allows the Bureau of Ocean Energy Management (BOEM) to assess the localization efficacy of towed PAM arrays proposed in mitigation and monitoring plans for offshore wind farm development and other operations. Simulations of a 200-m aperture array were run for three marine mammal signal types of interest: sperm whale, right whale, and beaked whale. The ability to localize a marine mammal call using PAM systems commonly deployed for mitigation surveys conducted in support of offshore wind farm development requires several conditions and assumptions. In order to localize, the call must first be detected. A detection's range will be dictated by the received amplitude of the signal, which in turn depends on the species, distance, and relative orientation to the receiver, as well as the noise conditions of the monitoring environment. The goal of this project was the development of an

¹ University of California, UC San Diego Scripps Institution of Oceanography; 9500 Gilman Drive; La Jolla, CA, 92093

² University of Washington; 4333 Brooklyn Ave NE, Box 359472; Seattle, WA 98195

algorithm and user interface with the intent to enable BOEM personnel to input proposed array specifications and determine the theoretical localization capability for low-, mid-, and high-frequency cetaceans within 5 km of the array.

BACKGROUND: Passive acoustic monitoring (PAM) has become a widely-used mitigation in order to detect marine mammal species and ensure they remain outside of protective exclusion zones during the use of active sound sources in order to prevent injury to these protected species. PAM can support and validate visual observation efforts but, more importantly, because PAM is not reliant on good visibility or good weather to function efficiently, it presents an additional mitigation technique during periods of low visibility when visual observations are not possible. Lessees in the renewable energy industry have requested, and have been approved, to conduct 24-hour high resolution geophysical (HRG) surveys. Round-the-clock operations are important to the industry considering the tremendous mobilization and operational costs associated with these surveys.

Towed PAM is one of the mitigations proposed to be used during nighttime operations to not only detect vocalizing marine mammals, but to help ensure that animals remain outside of the exclusion zone. However, in order to initiate necessary mitigative measures, PAM operators have to be able to determine the location of marine mammals relative to the PAM array itself and, ultimately, relative to the sound source or sources. To date, there are few data or algorithms readily available that assess the localization accuracy for the ad hoc towed PAM array configurations typically proposed to Bureau of Ocean Energy Management (BOEM); the available data is also limited for a variety of marine mammal signals in different frequency ranges. BOEM therefore has no way of determining how effective the localizing abilities of the arrays proposed by developers for mitigation purposes are for the various types of calls produced by the marine mammal species that occur within wind energy areas in the Atlantic Ocean. Determining effective mitigations that balance protection of marine mammals with the development of offshore renewable energy requires an understanding of the localization accuracy of towed PAM arrays.

OBJECTIVES: The study has two objectives. The first is to a) identify, examine, and understand the critical parameters needed to design a towed PAM array; b) formulate a methodology that will quantify a towed PAM array's localization performance; and c) document the theories, concepts, and approach necessary to explain the performance of a towed PAM array.

The second objective is to develop an algorithm that will assess and visualize the localization performance of future array designs, which may be proposed to BOEM, and identify steps that may/should be taken to improve or optimize the performance of the proposed towed PAM array design.

METHODS: A numerical model for simulating the localization performance of a three- or four-hydrophone towed PAM array on multiple species clusters was developed to allow BOEM to assess the localization efficacy of towed PAM arrays proposed in mitigation and monitoring plans for offshore wind farm development and other operations. Simulations of a 200-m aperture array were run for three marine mammal signal types of interest: sperm whale, right whale, and beaked whale. The ability to localize a marine mammal call using PAM systems commonly deployed for mitigation surveys conducted in support of offshore wind farm development requires several conditions and assumptions. In order to localize, a call must first be detected. The detection's range will be dictated by the received amplitude of the signal, which in turn depends on the species, distance, and relative orientation to the receiver, as well as the noise conditions of the monitoring environment. The goal of this project was the development of an algorithm and user interface with the intent to enable BOEM personnel to

input proposed array specifications and determine the theoretical localization capability for low-, mid-, and high-frequency cetaceans within 5 km of the array.

The parameters set by the project required the use of curved-wavefront localization (CWL), which is equivalent to hyperbolic localization in the time domain. Roughly speaking, a CWL becomes possible whenever a source is close enough to the array such that the apparent azimuth of the source will appear to vary along the array, when measured by pairs of adjacent hydrophones along the array. If expressed in terms of hyperbolic localization, CWL means that hyperbolas produced by pairs of hydrophones will eventually intersect and not become asymptotically parallel at large ranges. The term “curved wavefront localization” arises because in order for an array to localize in range, the wavefront of a signal passing over an array cannot be a plane wave structure and must display curvature.

The fundamental approach of the algorithm development was to run multiple iterations of a marine mammal localization problem, randomly varying relevant parameters to estimate the bias and variance of the resulting range estimates. Each iteration generated a random realization of a marine mammal signal at each receiving hydrophone by randomly generating different source parameters, hydrophone positions, and the background noise time series. The simulated time series were then cross-correlated between hydrophones, and the desired localization algorithm applied. The process was repeated at all grid locations. Then, additional iterations were conducted to build a distribution of range estimates from which the bias and variance of the range estimate can be computed for every grid point.

Two localization algorithms were applied, based on array geometries: a three-element case for the time-of-arrival (TOA) algorithm (where the hydrophones can have any spacing) and a four-element case for the “cross-fixing” algorithm (where the hydrophones are divided into two pairs to form two short sub-apertures). For both approaches, the mean (unperturbed) positions of the hydrophone elements were used in the localization calculation. Localization algorithms that require a larger number of hydrophones were not modeled because the majority of existing systems do not use more than four hydrophones for localization during real-time mitigation monitoring, and because the determining factor for the range resolution of a system is the total aperture (i.e., maximum separation between array hydrophones). A maximum 5-km radius monitoring grid with 1-m resolution was used to evaluate localizations at each grid point of interest within the algorithm.

RESULTS: The algorithm was tested using a grid search method against the dataset published by Abadi et al. (2015, 2017). This dataset is key to the algorithm testing because it provides a peer-review standard that statistically correlates acoustic detections with visual observations. The algorithm was developed to enhance localization capabilities where no direct path exists between the source and receiver.

CONCLUSIONS: The main insight from these simulations was that the uncertainty in range estimation is dominated by the uncertainty in array element position, likely due to the fact that the specified noise levels are too low, having been derived for measurements from a stationary platform well away from vessel noise. The introduction of vessel noise in towed PAM array systems is expected to increase localization uncertainty, when signals are detected. In consultation with BOEM, example background noise profiles from actual PAM operations will be explored that can be used to determine when background noise levels become a determining factor for PAM array performance, as a means to test simulations for conditions that may be present during offshore wind farm development.

STUDY PRODUCTS: The algorithm consists of a spreadsheet, a platform-independent stand-alone software package, and a user manual. The spreadsheet contains the formulas from the study, so that the user can quickly determine whether a given towed array configuration has any chance of meeting the localization requirements of an application. The stand-alone software package is written in MATLAB but will be processed with the MATLAB compiler to generate a stand-alone application package that can be distributed on a royalty-free basis. The stand-alone application does not require MATLAB to be executable. The advantage of this approach is that the MATLAB compiler can generate versions compatible with most hardware platforms, including Microsoft Windows and Apple operating systems. It can also generate web-based versions and stand-alone versions on a desktop or laptop computer, so that BOEM could put the tool online for public use.

1. Thode A, Abadie S, Barkaszi MJ. 2021. Optimization of Towed Passive Acoustic Monitoring (PAM) Array Design and Performance Study (Passive Acoustic Monitoring Study). Sterling (VA): US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2021-086. 32p.
2. Spreadsheet
3. Platform-dependent stand-alone software package
4. User's Manual