# STATEMENT OF WORK

## Substrate-borne Vibroacoustic Disturbances from Offshore Wind Construction: Measurements, Physical Characteristics, and Propagation (NT-23-11)

## PURPOSE

This proposed study is to make measurements and investigate the physical characteristics and propagation of substrate-borne mechanical waves through seabed from offshore wind facility construction and operations. Although environmental impacts from substrate-borne particle motion from pile driving have been widely recognized as potential major effects on marine benthic organisms, very little research has been conducted to address these types of vibroacoustic disturbances (Popper & Hawkins, 2018; Hawkins et al., 2021). Therefore, information is critically needed concerning the physics and propagation of vibroacoustic disturbances from such activities (Popper et al., 2022). In addition, this study would explore additional data collection methods and identify the most appropriate geoacoustic sensor(s) to obtain substrate-borne vibroacoustic signals at different ranges and layers of the sediment, and to develop source and propagation to predict impact zones.

Furthermore, though this study is proposed to address substrate-borne vibroacoustic characteristics and propagation from offshore wind farm construction and operations, results from this study have wide application for many marine engineering activities that are coupled with seabed, such as construction and operations of marine energy converters, subsea drilling and dredging, offshore structure removal, and deep-sea mining.

## BACKGROUND

Pile driving for offshore wind farm construction generates various substrate-borne vibroacoustic disturbances or vibration, including compressional and shear waves that propagate within the sediment, as well as interface (Scholte) waves along the seabed (Miller et al., 2016). Some of these wave disturbances could contain high energy that, in cases of land-based impact pile driving, could cause structural damage to nearby buildings (Whyley and Sarsby, 1992). There is also increasing realization that fishes and marine invertebrates that primarily sense sound as a form of particle motion are likely affected by substrate-borne vibrations (Popper and Hawkins, 2018; Hawkins et al., 2021). Benthic-dwelling species are, particularly, sensitive to and could potentially be impacted by substrate-borne vibration (Roberts and Breithaupt, 2016; Roberts et al., 2016a; 2016b; Roberts and Elliott, 2017).

Currently there is very limited information on the physical characteristics and propagation of substrate-borne mechanical waves, and there is no dedicated and systematic study to address these topics (e.g., Miller et al., 2016; Hazelwood and Macey, 2016; Hazelwood et al., 2018; Potty, 2020). Results from the recent BOEM-funded Block Island Wind Farm study showed that at horizontal ranges of 500 m and 1,500 m, particle acceleration levels measured on the seabed were well above the behavioral sensitivity for the Atlantic salmon, plaice, dab, and Atlantic cod up to a frequency of approximately 300 Hz (HRD, 2019). Starting in FY2022, BOEM has been funding another study to conduct in-depth substrate-borne mechanical wave measurements

during RODEO and Coastal Virginia Offshore Wind (HDR, 2020) projects (AT-22-08; contract no. M22AC00006). However, data collection from these studies are mainly focused on water-borne acoustic pressure and particle motion, with substrate-borne data only available from one geosled and one Ocean Bottom Recorder (OBX) at limited horizontal distances between 725 and 1,150 m. Without additional data collected at a wide range of distances, it is impossible to gain enough insight of wave propagation to be able to sufficiently model this complex phenomenon accurately.

This proposed study would contribute to knowledge on substrate-borne mechanical waves from BOEM-regulated marine engineering activities, including offshore wind construction. The information obtained from this study would greatly assist BOEM decision-making using scientific knowledge that is first in class. In addition, this study would explore additional data collection methods and identify the most appropriate geoacoustic sensor(s) to obtain substrate-borne vibroacoustic signals at different ranges and layers of the sediment.

## REFERENCES


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Roberts, L, Elliott, M. 2017. Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos. Sci Total Environ. 595,255-268.

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## OBJECTIVES

The objectives of this study are: (1) Establish appropriate methodology to collect and analyze substrate-borne vibroacoustic disturbances from offshore wind construction and operations that could potentially affect benthic ecological communities, and (2) Obtain critical knowledge on the characteristics and propagation of different types of substrate-borne mechanical waves at various source ranges and at various sediment depths for impact assessment modeling.

Some of the key questions to be addressed are:

1. What are the appropriate methods to collect substrate-borne vibroacoustic disturbance data from an offshore wind construction project that are relevant to environmental impact assessment (including the suitable geoacoustic sensors, signal processing, and acoustic metrices)?
2. What are the types of substrate-borne vibroacoustic disturbances from offshore wind construction activities and how are they related (e.g., compressional, shear, and interface waves)?
3. What are the physical characteristics of substrate-borne mechanical waves from offshore wind construction activities (e.g., amplitude, frequency, directivity, propagation speed, duty cycle, etc.)?
4. What are the propagation characteristics of substrate-borne mechanical waves from offshore wind construction activities and how they relate to different types of sediments (e.g., decay rate over distance and depth, frequency-dependent propagation, etc.)?
5. How can substrate-borne mechanical waves be modeled for their physical characteristics and propagation so ranges to effects can be predicted for impact assessment?

## DESCRIPTION OF WORK

**Methods:** Prior to field data collection, extensive literature reviews would be conducted to identify the type(s) of substrate-borne acoustic waves that are most likely to cause adverse effects on benthic organisms, and the most appropriate geoacoustic sensors to collect these vibroacoustic data. Subsequently, geoacoustic sensors will be deployed at selected wind project areas at several different distances and azimuths from sources of interest to collect substrate-borne vibroacoustic data during wind farm construction and/or operations. Additionally, geophysical properties (e.g., grain size, porosity, layer thickness) and, if possible, benthic community data of the substrate between the source and the sensors will be collected to understand substrate-borne vibroacoustic propagation conditions in the study area. Finally, for the optional task, the results will be used to construct generic substrate-borne vibroacoustic range-dependent propagation models that incorporate source characteristics and environmental parameters.

## TASKS

Task 1: Conduct a post award project kick-off meeting.

a. Schedule a post award online project kick-off meeting that includes the CO, COR, BOEM Environmental Program representative, principal investigate, and other key personnel involved in the study.
b. Discuss with BOEM experts on the scope and timeline of the project.

Delivery 1: Provide a summary of the post award project kick-off meeting to BOEM.

Task 2: Develop study plans to collect substrate-borne vibroacoustic wave data during offshore wind construction and/or operations and identify analytical method(s) for data processing so the desired quantities listed in Deliverable 1 can be accurately obtained.

a. Work with BOEM experts and offshore wind developers to develop a field plan to collect substrate-borne vibroacoustic data at agree-upon locations and time during impact and/or vibratory pile driving for offshore wind farm construction and/or from wind farm operations.
b. Work with BOEM experts and offshore wind developers to develop a field plan to collect geophysical properties data (e.g., type, grain size, porosity, layer thickness, etc.) of the substrate between the source and receivers
c. Work with BOEM experts and offshore wind developers to develop a field plan to collect benthic biological characteristics (e.g., types of benthic communities, species diversity, etc.) between the source and receivers
d. Work with BOEM experts to develop a data processing plan to analyze physical parameters and quantities of substrate-borne acoustic waves as well as propagation characteristics
e. Work with BOEM experts to develop a plan to construct range-dependent substrate-borne vibroacoustic wave propagation models using environmental

parameters (e.g., geophysical characteristics of the substrate, benthic community composition, etc.)

Deliverable 2: Study plans presented to BOEM experts for discussion and approval.

Task 3: Conduct a literature review of existing papers that discuss sediment-borne acoustic waves generated from marine engineering activities, with a preliminary understanding of the type of vibroacoustic waves that are likely to impact benthic ecological communities.

a. Compile a list of literature that discuss the physics of sediment-borne vibroacoustic disturbances from marine engineering activities, such as pile driving, drilling, etc.
b. Identify the type(s) of sediment-borne vibroacoustic disturbances (longitudinal/compressional and transverse waves in the sediment, interface/Scholte wave on the seabed) that is/are most likely to affect benthic organisms.
c. Discuss with BOEM experts and agree upon a set of physical parameters amplitude, frequency/PSD, directivity, etc.) of the sediment-borne vibroacoustic disturbances that should be investigated; determine the units of these parameters so the results will be readily comparable and consistent with widely accepted practices.
d. Based on the review and discussion, identify the geoacoustic sensors that are most appropriate and suitable for data collection of substrate-borne acoustic waves.

Deliverable 3: A summary report that includes (1) literature review of sediment-borne vibroacoustic disturbances and their potential biological and ecological effects, along with an Endnote library (or comparable reference library such as Zotero) with PDF files of the papers reviewed; and (2) discussion with BOEM experts concerning physical parameters and units of substrate-borne acoustic waves to be investigated in this study.

Task 4: Field data collection of sediment core samples and substrate-borne acoustic wave data

a. Work with BOEM experts and offshore wind developer(s) to collect substrate core samples at agreed-upon locations along the range and azimuths.
b. Work with BOEM experts and offshore wind developer(s) to deploy and retrieve geoacoustic sensors at agreed-upon locations and time along the range and azimuths.
c. Work with BOEM experts on initial QA/QC of collected raw data.

Deliverable 4: Sediment core data and raw acoustic data collected in the field and associated metadata.

Task 5: Data analysis of substrate-borne acoustic wave physical parameters and propagation characteristics

a. Develop signal processing software to investigate substrate-borne acoustic wave physical parameters and propagation characteristics
b. Quality control check and revise the software to remove errors and fine tune the software to generate the best output format.
c. Conduct a thorough analysis of the entire datasets collected during the study period; compute all desired physical parameters and quantifies of substrate-borne acoustic waves
d. Incorporate sediment core sample data and conduct a comprehensive analysis of vibroacoustic datasets collected at different distances and azimuths to address propagation characteristics in the study area

Deliverable 5: An output of results and signal processing codes used to generate the results to be shared with BOEM experts and be made open-source.

Task 6: Interpret results. The analysis and interpretation of the results would emphasize the following areas:

a. The rate of decay of different types of sediment-borne acoustic waves based on data collected at different distances
b. The mechanism that causes the variations of the physical parameters (such as amplitude, frequency/PSD, and directivity) of the data that are collected at different distances and azimuths (with potentially different sediment types)
c. The potential range of effects on benthic organisms and communities based on current knowledge

Deliverable 6: A summary of analysis and interpretation of the results on sediment-borne vibroacoustic disturbances and potential effects on benthic organisms and communities.

Task 7 (Optional): Develop a preliminary propagation model for substrate-borne acoustic waves.

a. Develop a preliminary propagation model or similar approaches that could predict the propagation of sediment-borne acoustic waves given known environmental variables, including sediment types and characteristics and benthic community information.
b. Compare the modeling results with measurements at specific distance to gain additional knowledge on the propagation of substrate-borne acoustic waves.

Deliverable 7: Software and/or programming codes for the developed model(s).

Task 8: Work with BOEM experts on future directions on studies of substrate-borne acoustic waves and their potential effects on marine benthic ecological communities.

a. Work with BOEM experts on recommendations for future data collection methodologies, including, but not limited to, the need to develop/improve geoacoustic sensors to collect biologically-relevant substrate-borne acoustic data, analytical methods for data analyses, number of locations (range and azimuth from the source) needed for data collection, sensor depth in the water column and sediment.
b. Work with BOEM experts on recommendations for future modeling to predict ranges to impacts, including the types of numerical approaches, model complexities, and margin of errors.
c. Work with BOEM experts on recommendations or suggestions regarding how substrate-borne acoustic waves from pile driving or turbine operations could be simulated in laboratory environment on animal exposure studies.

Deliverable 8: A summary report (or report chapter, see below) of recommendations for future research on sediment-borne vibroacoustic disturbances and their effects on the benthic ecological communities.

Task 9: Reports, presentation(s), and publication(s).

a. Work with BOEM experts on quarterly reports that summarize progresses of this study.
b. Work with BOEM experts on the draft and final reports and technical summaries that details all the tasks and results listed above.
c. Work with BOEM experts on presentation(s) at scientific conferences on the study
d. Work with BOEM experts on peer-reviewed publication(s) on the study of substrate-borne acoustic waves from this study.

Deliverable 9: Quarterly reports, draft report and technical summary, final report and technical summary, presentation(s), and peer-reviewed publication(s).

**ESPIS Data Deliverables Requirements**

- Final Report and Technical Summary: The copies of the narratives of study results in both the MS Word and Adobe Acrobat (PDF/A) formats, without any password protections, following the ESP Report Specifications.
- Study Footprint: The geographic information that enables the referencing of the study using a GIS, following the study footprint specifications.
- Study Footprint Metadata: The scientific attribution information required to enhance discoverability of the study in the ESPIS system and third-party sites (such as data.gov), following the study footprint metadata specifications.

- Study Map: The study area map embedded in the Final Report and Technical Summary that depicts the study footprint and that is cited in the study footprint metadata.
- Federal Geographic Data Committee (FGDC) compliant metadata for each scientific dataset: The scientific, technical, and administrative information for each coherent unit of scientific data, including the physical medium, file information, volume, and access URL, when applicable.
- Include boilerplate language in every ESP contract/agreement.
    - Copy of related publications: "The manuscripts of scholarly publications and conference presentations for research funded by this [contract/ agreement] for free and unlimited use by BOEM staff, which may take the form of a full-text, final, pre-publication copy of the related publication in cases that the publisher enforces pay for access or copyright restrictions."
    - Bibliographic information for related publications: "The information on each related publication needed for formatting CSE [Council of Science Editors] bibliographies using the name-date system

**Data Management Plan**

- All data (including raw acoustic datasets and associated metadata) from this study will be delivered to BOEM and shared at a specific public repository (e.g., National Center for Environmental Information).
- All acoustic modeling codes developed specifically for this study will be shared with BOEM and made open-source.
- Existing modeling software used in this study but are not developed specifically for this study may be proprietary, however, BOEM will prioritize the use of open-source software and modeling tools when considering award.

**Scientific Integrity**

Scientific integrity is vital to Department of the Interior (DOI) activities under which scientific research, data, summaries, syntheses, interpretations, presentations, and/or publications are developed and used. Failure to uphold the highest degree of scientific integrity will result not only in potentially flawed scientific results, interpretations, and applications but will damage DOI's reputation and ability to uphold the public's trust. All work performed must comply with the DOI Scientific Integrity Policy posted to http://www.doi.gov, or its equivalent as provided by their organization or State law.

## AWARD INFORMATION

Total project allocation for this study is $1.5 million from FY23 to FY26. A preliminary breakout of funding amount is listed below but can be amended as needed per BOEM approval. No study proposal may have a budget exceeding $1 million in funds requested from BOEM. Matching contributions from the applicant are strongly recommended. BOEM anticipates that there would be a single award as part of this project.

FY23: $500,000

FY24: $500,000

FY25: $300,000

FY26: $200,000

## DELIVERABLES

**(1.) Post-award Teleconference:** Under the moderation of the BOEM project officer (PO) and the BSEE contract officer for this cooperative agreement (CO), a post-award teleconference will be conducted. The participants will be the PO, CO, BOEM DES contact, and the principal investigator who performs the study. The teleconference will be conducted as soon after the BOEM funding award as is practical under the scheduling constraints of the participants.

A synopsis of the kick-off meeting will be drafted by the PO and distributed to the Chief of the Environmental Sciences Division and to all the participants of the teleconference.

**(2.) Study Plan(s):** The principal investigator shall produce study plan(s) detailing: sensor deployment, acoustic and geophysical data collection, and data analysis and dissemination.

**(3.) Literature Review:** The principal investigator shall submit a summary report on literature review with Endnote library and PDF files of papers reviewed to BOEM.

**(4.) Substrate-borne vibration data (raw acoustic data) and associated metadata (including sediment core sample data):** The principal investigator shall submit all datasets (including raw acoustic data and associated metadata such as sediment core sample data, other environmental variables, and sensor specifications) to BOEM at the end of the project.

**(5.) Results and modeling codes:** The principal investigator shall submit an output of results from the test run and signal processing codes used to generate the results to BOEM at the end of the project.

**(6.) Summary of analysis and interpretation:** The principal investigator shall include the summary of analysis and interpretation of the results on sediment-borne vibroacoustic disturbances and potential effects on benthic organisms and communities in the draft and final reports submitted to BOEM at the end of the project.

**(7.) Preliminary Propagation Model (Optional):** The principal investigator shall provide the software and/or programming codes for the developed model(s) with BOEM at the end of the project.

**(8.) Directions on Future Research:** The principal investigator shall include future directions on studies of substrate-borne acoustic waves and their potential effects on marine benthic ecological communities in the draft and final reports submitted to BOEM at the end of the project.

**(9a.) Quarterly Progress Reports:** The principal investigator shall produce quarterly reports briefly stating: progress made in the past quarter; any particular problems needing BOEM intervention to resolve; and anticipated progress to made in the next quarter.

**(9b.) Draft Final Report and Technical Summary:** The principal investigator shall complete and submit a draft final report and draft technical summary to BOEM for scientific peer and editorial review. The report and technical summary shall be in the format specified at

http://www.boem.gov/Environmental-Studies-Program-Report-Specifications/. The report shall contain the following language concerning its availability in ESPIS:

"To download a PDF file of this Environmental Studies Program report, go to the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program Information System website and search on OCS Study BOEM xxxx-xxx.", where xxxx-xxx will be replaced with the assigned BOEM study number.

In addition, in the Acknowledgement of Sponsorship Section, the report shall contain the following disclaimer and acknowledgement language:

"Disclaimer: This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use."

and

"Acknowledgement: Study collaboration and funding were provided by the U.S. Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program, Washington, DC under Agreement Number _____."

**(9c.) Final Report and Final Technical Summary**: The principal investigator shall revise the draft final report and draft technical summary according to feedback given by BOEM reviewers and the PO. She shall provide three high-quality, bound paper copies of the revised final report suitable for reproduction and five (5) CD-ROMs or DVDs each containing searchable text in the pdf format of the final report with book marks and a pdf copy of the final technical summary.

**Deliverables, Due Dates, and Distribution**

| Deliverable | Distribution | Due Date |
|---|---|---|
| A. Post Award Teleconference and Summary Notes | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>CO—One (1) electronic copy<br>All other participants in the teleconference—One (1) electronic copy | As soon as practical after BOEM funding award<br>Summary Notes due approximately one (1) week after teleconference |

| Deliverable | Distribution | Due Date |
|---|---|---|
| B. Study Plan(s) | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Within two weeks after the Principal Investigator and BOEM reaches agreement on study design and data collection, analysis, and dissemination processes. |
| C. Literature Review and Endnote Library with PDF Files of Papers Reviewed | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Within three months after the Principal Investigator and BOEM reaches agreement on study design and data collection, analysis, and dissemination processes. |
| D. Substrate-borne acoustic data (raw data) and associated metadata | PO—One (1) electronic copy | Due two (2) months prior to the end of the period of performance, along with Draft Report and Technical Summary |
| E. Output results and modeling codes | ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Due two (2) months prior to the end of the period of performance, along with Draft Report and Technical Summary |
| F. Summary of analysis and interpretation | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Due two (2) months prior to the end of the period of performance, to be included in the Draft Report and Technical Summary and Final Report |
| G. Preliminary Propagation Model (Optional) | Chief, DES—One (1) electronic copy | Due two (2) months prior to the end of the period of performance, along with |

| Deliverable | Distribution | Due Date |
|---|---|---|
| | ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Draft Report and Technical Summary |
| H. Directions on Future Research | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Due two (2) months prior to the end of the period of performance, to be included in the Draft Report and Technical Summary and Final Report |
| I(1). Quarterly Reports | Chief, DES—One (1) electronic copy<br>ESP Rep—One (1) electronic copy<br>PO—One (1) electronic copy<br>CO—One (1) electronic copy | Within four (4) months from award and Quarterly afterward. |
| I(2). Draft Report and Technical Summary | Chief, DES—One (1) electronic copy (in MS Word format)<br>ESP Rep—One (1) electronic copy (in MS Word format)<br>PO—One (1) electronic copy (MS Word) for report<br>CO—One (1) electronic copy of transmittal letter only | Draft due two (2) months prior to the end of the period of performance |
| I(3). Final Report and Technical Summary | Chief, DES—One electronic copy (in pdf format)<br>ESP Rep—One (1) electronic copy (in pdf format)<br>PO—One (1) electronic copy (in pdf format), three (3) | Before the end of the period of performance |

| Deliverable | Distribution | Due Date |
|---|---|---|
| | bound paper copies and five (5) CD-ROM copies, containing both the technical report and the technical summary in Adobe Acrobat (.pdf) format and labeled with the study title, BOEM report number, BOEM contract number, contractor name and date<br><br>CO—One (1) copy transmittal letter only | |