Measuring Changes in Ambient Noise Levels from the Installation and Operation of a Wave Energy Converter in the Coastal Ocean

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PROJECT INFORMATION
Federal Program Officer Name: Tim Ramsey
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LONG-TERM GOALS
Ecosystem impacts resulting from elevated underwater noise levels generated by anthropogenic activities in the coastal ocean are poorly understood. Ambient noise is an important habitat component for marine mammals and fish that use sound for essential functions such as communication, navigation, and foraging. Questions surrounding the amplitude and frequency distribution of noise emissions from renewable wave energy conversion (WEC) projects during their construction and operation present concerns for long-term consequences in marine habitats. Goals of this project are to provide new information and a framework for measuring acoustic emissions from shallow water WECs in high energy environments in close proximity to the surf zone. This research will assist future marine renewable energy projects for permitting and licensing efforts by providing background noise levels and filling existing knowledge gaps with technical guidance for sound level measurements associated with WEC projects in challenging shallow water marine environments.

OBJECTIVES
The scientific and technological objectives of the project include: 1) quantitative measurements of broadband (10Hz – 13 kHz) sound pressure levels before and during the installation and operation of a surge type wave energy conversion (WEC) device in the shallow coastal waters off the north Oregon coast; 2) time/frequency characterizations of noise emissions surrounding the project through a variety of environmental conditions; 3) evaluation of ambient noise levels measured during WEC construction and operation within the framework of baseline recordings taken in the area; 4) quantitative comparisons of WEC generated noise emissions with natural and anthropogenic acoustic sources found near the project site.

APPROACH

Data Collection and Instrumentation
1) Bottom-mounted hydrophone lander frames (temporal characterization)
Two, passive acoustic seafloor hydrophone mooring platforms were deployed at the project site in 10 m and 13 m water depths separated by a cross-shore distance of 160 m and 540 m respectively from the planned surgeWEC™ device location provided by Resolute Marine Energy, Inc. (Fig. 1). The hydrophone landers were deployed and recovered during the spring, summer and fall on 4-6 week intervals to avoid being buried by sediment in the highly dynamic nearshore.

The semi-trawl protected lander frames consist of hollow aluminum tubing weighted with lead or concrete ballast and have an estimated circular seafloor footprint of roughly 3 square meters ($r \approx 1$ m) and a vertical extent of nearly 2 m (Fig. 2). In addition, an acoustic release recovery system allows the entire instrument package and frame to remain fully submerged with no surface expression throughout the deployment period. During recovery operations, an acoustic command from the support vessel initiated the release of a messenger float to the surface, enabling the lander frame and all components to be lifted and recovered from the seafloor.
The hydrophone instruments were built and tested at OSU’s Cooperative Institute for Marine Resources Studies and NOAA/Pacific Marine Environmental Laboratory Acoustics Program and consist of an acoustic data logging system housed in a composite pressure case. The hydrophone instrument is a low-power 16-bit data acquisition system and combined pre-amplifier using omni-directional, wideband hydrophone sensors from High Tech, Inc. (HTI-92-WB) with sensitivities -180 dB re: 1 V/μPa and a built in 1-pole high pass filter with corner frequency $f_c$ 50 Hz. The acquisition system continuously records 2 channel data at a sample rate of 32 kHz, storing to compact flash every 15 minutes at a file size of 113 MB. Prior to analog-to-digital conversion, the signal is conditioned by a pre-amplifier with a pre-whitening filter which helps de-emphasize the ambient noise spectrum below 20 Hz so that the 16-bit dynamic range can be fully utilized. The pre-amplifier consists of a series of gain stages with filters including two one-pole high-pass filters with cut-off frequencies at 1 Hz and 20 Hz respectively. The last stage of the pre-amplifier is an 8-pole elliptical anti-aliasing filter with a cut-off frequency ($f_c$) at 13 kHz. Prior to data analysis, the
recorded signal is converted to sound pressure relative to μPa by removing these instrument responses.

2) Acoustic drifting underwater hydrophone (ADUH) deployments
A series of short-term “snap shot” type acoustic recordings were collected using an autonomous drifting underwater hydrophone (ADUH) system to provide spatially dependent ambient noise level measurements in the project area. The ADUH system consists of a 3 m long spar buoy with GPS logger, shock cord, static line, heave plate and a hydrophone instrument suspended 7 m below the sea surface. The internal components of the ADUH hydrophones are identical to the data acquisition system of the lander hydrophones except for a different model of HTI omni-directional sensor (-174 dB re: 1 V/μPa) and a smaller titanium housing. Each drift consisted of up to 1 hour of continuous recording prior to recovery.

Data Analysis
After removing the instrument response from the hydroacoustic waveform time series’ and converting to μPa, spectral estimates are calculated from FFT using a 1 second hanning window applied to 1 second data frames with no overlap. Spectral calculations are then averaged over 1 hour time periods for temporal comparisons with environmental conditions. Root mean square sound pressure levels ($SPL_{rms}$) are calculated from 10 second data frames for the fixed lander stations and 30 second data frames including a 50 Hz high pass filter for the drifting hydrophones to avoid flow noise. $SPL_{rms}$ is calculated as:

$$ SPL_{rms} = 20\log_{10}\left(\frac{p_{rms}}{p_{ref}}\right) $$

with units reported in (dB re 1 μPa).

Key personnel for the project include:
Joe Haxel – Cooperative Institute for Marine Resources Studies Oregon State University
– Principle Investigator Acoustics Program Coordination of ship logistics, deployment/recovery operations, drifting hydrophone measurements, data analysis and reporting
Sarah Henkel – Department of Integrative Biology, Oregon State University
– Project reporting and management
Haru Matsumoto - Cooperative Institute for Marine Resources Studies Oregon State University
– Chief Engineer Acoustics Program
– Build and test hydrophone instrumentation and data acquisition systems

WORK COMPLETED
After the first budget period, in December 2016 the project reached a mutual termination, No-Go decision point resulting from RME surgeWEC deployment schedule uncertainties, thus restricting the project to pre-installation baseline recordings. Tasks completed during the
reporting period therefore include baseline acoustic recording analysis and final project reporting to the Department of Energy project management team.

RESULTS
A significant gap in knowledge exists for measured noise levels in Oregon’s high-energy, shallow coastal water environment. Measurements reported here, represent the some of the first recordings specific to the Oregon coast at these shallow depths.

1) Fixed Station Hydrophone Data
High fluid velocities associated with wave orbital motions in these shallow waters create substantial flow noise contamination. As hypothesized, the recorded acoustic levels were strongly influenced by the proximity of the lander hydrophone receivers to the breaking surf zone at Camp Rilea. The low frequency acoustic energy generated by the shock impact of breaking waves, as well as the low frequency pulsation of bubble clouds during wave energy dissipation are convolved with non-acoustic pressure fluctuations (flow noise) at the fluid/sensor interface. Likewise, simple variations in hydrostatic pressure associated with the vertically oscillating water column also influence the low frequency end of the pressure spectrum. These confounding factors contaminate the low frequency acoustic measurements, making estimates of absolute acoustic energy levels challenging. Spectrograms derived from hourly averages of acoustic recordings during the July deployment show the strong influence of flow noise on spectral levels below 500 Hz (black dashed line; Fig. 3). Due to its shallower depth and closer proximity to the surf zone, the 10 m station experienced higher wideband energy levels compared to the 13 m station. Periods with elevated incident wave energy appear as brighter orange and yellow colored areas of the spectrograms mostly concentrated in frequencies below 500 Hz (e.g. 07/03, 07/10, 07/31). Thus, frequencies 500 Hz – 13 kHz provide reliable acoustic measurements void of flow noise contamination and describe acoustic variability associated with surf and wind generated surface processes.

Figure 3. Spectrograms showing the hourly averaged, acoustic energy levels as a function of frequency and time for the 10 m and 13 m depth hydrophone lander stations during the summer deployment. The black dashed line indicates the 500 Hz frequency on the log_{10} vertical axis.
Nearby meteorological and wave climate measurements were used to investigate environmentally forced underwater noise level variability at the Camp Rilea hydrophone lander stations. Wave and wind speed measurements from nearby buoys and meteorological stations were used for comparisons of noise levels. Figure 4 shows comparisons of noise levels (500 Hz – 13 kHz) as a function of both Hs and Tp at the Camp Rilea hydrophone stations. Patterns in elevated noise levels show significant correspondence with rising Hs at both inshore and offshore stations. Meanwhile, during similar wave height conditions, increasing Tp lack a significant rise in noise levels, suggesting wave heights may have a stronger influence on noise generating processes during dissipation in the surf zone than extending the surface waves to longer periods. This may be particularly true for short period, locally generated wind waves as amplitudes increase.

Figure 4. Underwater noise Band Pressure Levels (BPL; 500 Hz – 13 kHz) as a function of significant wave heights (Hs) and dominant wave periods (Tp) for inshore (10 m) and offshore (13 m) hydrophone stations.

Percentile distributions of underwater spectral noise levels (Fig. 5) illustrate typical (50th) acoustic conditions for the 10 and 13 m depth stations during the summer and fall deployment periods. Extreme noise levels (99th) show more complex frequency structure and occur during periods of elevated incident wave energy. The area of exaggerated noise levels between ~1.5 – 4 kHz in the 10 m station data is systematic and appears to be the result of cable vibration resonating near the sensor that is excited when wave orbitals reach higher velocities. 1 percentile curves show similar structure between the stations during the quietest conditions where surf generated noise is at a minimum. Empirical cumulative distribution functions of band limited (500 Hz – 13 kHz) SPLrms calculated from 10 second data frames during summer and fall recordings show the consistently higher noise levels at the inshore verses offshore stations (Fig. 6). The cumulative noise level distribution curves diverge steadily up to the 60th percentile, remaining nearly constant until diverging rapidly at extreme levels (> 95th percentile). In low energy conditions,
noise levels are nearly identical and slowly diverge as incident wave energy increases up until extreme conditions where the closer proximity of the inshore station to the surf zone provides a rapid increase in noise levels.

![Figure 5](image)

**Figure 5.** Frequency dependent percentile distributions (1st, 50th, 99th) of noise levels from hourly averages at the inshore (left) and offshore (right) hydrophone stations. 50th percentile curves represent “typical” acoustic conditions recorded at each station during summer and fall deployments.

![Figure 6](image)

**Figure 6.** Empirical cumulative distribution functions of SPL_{rms} at the onshore and offshore hydrophone lander stations during the summer and fall deployments calculated from 10 second data windows and high passed at 500 Hz.

2) **Drifting Hydrophone Data**

Acoustic recordings using the mobile ADUH platform were collected on 3 different days in the summer and fall during similar environmental conditions. Spectral analysis revealed surf generated noise from nearby breaking waves in the surf zone was a dominant sound source in frequencies ranging from 1-9 kHz. Meanwhile, flow noise associated with wave motions appeared to influence low frequency noise levels (f < 50 Hz) throughout the drifting recordings.
The compliance of the drifting hydrophone system significantly reduced the affected frequency range (by an order of magnitude). The spatial distributions of root mean square sound pressure levels ($\text{SPL}_{\text{rms}}$) averaged over 30 second periods and high pass filtered with a corner frequency $f_c = 50$ Hz to remove the influence of flow noise showed variability largely associated with differences in vessel traffic that was visually observed from the support vessel during the drifts (Fig. 7). The drift velocity dependence on wave and wind driven alongshore currents is readily observed in the direction and distance covered by the drifter despite nearly equal drifting periods for each deployment ($\sim$ 1 hr). Fifteen minute spectral averages from representative periods during each drift reveal a range of noise levels despite calm and very similar environmental conditions (Fig. 8). This variability is attributed the acoustic differences in light to medium nearby vessel traffic experienced during the drifting recordings. Recreational and commercial fishing vessels were observed within an estimated range of 0.25-3 km from the drifter during recordings.

**Figure 7.** Map view of $\text{SPL}_{\text{rms}}$ calculated values from ADUH hydrophone drifter recordings collected over 3 different days in the summer and fall. The proposed location of the RME surgeWEC device is shown as a red triangle and direction of the drifts is shown by arrows. The Sep 16 drift was deployed $\sim$1 km away from the RME position due to vessel traffic in the area.

**Figure 8.** Fifteen minute spectral averages of representative periods from ADUH drifts.
DELIVERABLES/DATA TRANSMISSIONS

1. **National Security**
   N/A

2. **Economic Development (e.g., new product lines, businesses, practices, increased efficiency, new manufacturing techniques)**
   N/A

3. **Quality of Life (e.g., public health, ecosystem health, coastal resource management)**
   The drifting hydrophone hardware and analysis techniques developed for this project are being implemented on a larger spatial scale for a gray whale noise exposure study on the central and southern Oregon coast. The ADUH drifter has been used extensively to record the spatial distribution of ambient noise levels surrounding critical marine habitat for seasonally resident and migrating gray whales along the Oregon coast. These recordings will be used to inform future long term hydrophone mooring installations in Oregon’s marine reserves.

4. **Science Education and Communication**
   Acoustic recordings from this study have been shared with Oregon Sea Grant to include in public presentations highlighting issues with marine underwater acoustics.

IMPACTS AND APPLICATIONS

1. **National Security**
   Results from this study will assist future marine renewable energy testing and development projects in similar environments by providing valuable information relevant to permit and licensing that fills existing knowledge gaps. In turn, marine renewable energy projects will become easier to pass through the environmental regulatory framework, furthering the MHK energy industry and easing the U.S. reliance on foreign oil.

2. **Economic Development (e.g., new product lines, businesses, practices, increased efficiency, new manufacturing techniques)**
   This study will help to alleviate environmental concerns regarding uncertainties associated with wave energy converter projects in the coastal ocean. These concerns have created significant financial burden in the regulatory process for WEC device developers. Results here will assist regulatory agencies and WEC developers in permitting and licensing reducing project costs overall and assisting the economic development of the WEC industry.
3. **Quality of Life (e.g., public health, ecosystem health, coastal resource management)**
   Results from this project will be used to help inform coastal resource managers and regulatory agencies on changes in underwater ambient noise levels that can be associated with WEC installation and operation activities in the coastal zone. This study provides a framework for assessing potential changes in ecosystem health related to noise level variability.

4. **Science Education and Communication**
   This project includes an outreach component with local students at Waldport High School. As part of a Career and Technical Education program, students fabricated the lander frames from aluminum stock and participated in a number of the deployment cruises. These students are now actively involved in data analysis of the acoustic time series identifying periods of marine mammal vocalizations, ship noise and weather generated signals. Additionally, all of the lander deployment and recovery operations were performed from the *M/V Forerunner*, a Clatsop Community College Marine and Environmental Research Training Station vessel with maritime sciences students as crew. This project has provided students ranging from the high school level through community college opportunities to engage in oceanographic research and technology development.

**RELATED PROJECTS**
The Northwest National Renewable Energy Center’s (NNRMEC) Pacific Marine Energy Center facilities offshore of Newport, Oregon are aimed at providing fully supported testing facilities for WEC developers. Technologies developed for this project have roots in acoustic technologies and applications from previous work at NNMREC. As NNMREC collaborators since 2009, Haxel and Matsumoto have developed acoustic expertise and capabilities that have benefited this project. [http://nnmrec.oregonstate.edu/](http://nnmrec.oregonstate.edu/)

**PUBLICATIONS**
None to date.

**PATENTS**
None

**WORK PLAN**
The project reached a No-Go decision point and was terminated after budget year 1. A final report was submitted to the U.S. Department of Energy.