FINAL SCIENTIFIC/TECHNICAL REPORT

U.S. Department of Energy – EERE

Title: Measuring changes in ambient noise levels from the installation and operation of a surge wave energy converter in the coastal ocean

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EXECUTIVE SUMMARY

Ecosystem impacts resulting from elevated underwater noise levels generated by anthropogenic activities in the coastal ocean are poorly understood and remain difficult to address as a result of a significant gap in knowledge for existing nearshore sound levels. 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 amplitudes, frequency distributions, and durations of noise emissions from renewable wave energy conversion (WEC)

projects during their construction and operation present concerns for long-term consequences in marine habitats.

To begin to address this knowledge gap, this project was originally awarded funding in 2013 to develop methods for the measurement of WEC generated acoustic emissions at the Northwest National Marine Renewable Energy Center's (NNMREC) mid-water North Energy Test Site on the central Oregon coast in cooperation Columbia Power Technologies, Inc. (CPT). After CPT withdrew their intent to test at NETS, a new partnership (under DOE agreement) between Resolute Marine Energy, Inc. (RME) and Oregon State University was developed for a modified acoustic study during a full scale, year-long surgeWEC demonstration at the Department of the Army's Camp Rilea small arms training facility on the north Oregon coast in 2016. The long-term goals of the project were to develop methods and a framework for measuring and assessing the potential impacts of acoustic emissions associated with a shallow water surgeWEC project in a high energy, nearshore environment just outside the surf zone.
Oregon's dynamic nearshore environment presents significant challenges for passive acoustic monitoring that include flow noise contamination from wave orbital motions, turbulence from breaking surf, equipment burial, and fishing pressure from sport and commercial crabbers. This project included 2 techniques for passive acoustic data collection: 1) campaign style deployments of fixed hydrophone lander stations to capture temporal variations in noise levels and 2) a drifting hydrophone system to record spatial variations within the project site. The hydrophone lander deployments were effective and economically feasible for enabling robust temporal measurements of ambient noise levels in a variety of sea state conditions. Limiting factors for the fixed stations included 1) a flow shield mitigation strategy failure in the first deployment resulting in significant wideband data contamination and 2) flow noise contamination of the unshielded sensors restricting valuable analysis to frequencies above 500 Hz for subsequent deployments. Drifting hydrophone measurements were also effective and economically feasible (although logistically challenging in the beginning of the project due to vessel time constraints) providing a spatial distribution of sound levels, comparisons of noise levels in varying levels of vessel traffic during similar sea states, and reducing the frequencies contaminated by flow noise to $f < 50$ Hz by an effective drifting hydrophone system design strategy.

Prior to completion, the project was terminated at a No-Go decision point resulting from RME surgeWEC deployment schedule uncertainty. Nevertheless, the results of this study can be used to help alleviate environmental concerns caused by a lack of information surrounding shallow water baseline acoustic conditions for future WEC testing at Camp Rilea, Oregon. These types of concerns have created significant financial burden in the regulatory and licensing process for WEC device developers. Truncated results from this project can still assist regulatory agencies and WEC developers in permitting and licensing, reducing project costs overall and assisting the economic development of the WEC industry, thus furthering the MHK energy industry and easing the U.S. reliance on foreign oil for energy production. Additionally, results from this project can be used to help inform coastal resource managers and regulatory agencies on existing baseline noise level variability and ecosystem health.

This project also included an outreach component with local students at Waldport High School on the central Oregon coast. As part of a Career and Technical Education program, students helped design and fabricate the lander frames from aluminum stock and participated in a number of the deployment cruises. These students were also 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 science 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.

GOALS, OBJECTIVES AND ACCOMPLISHMENTS

Goals of this project were to provide new information and a methodology for measuring and assessing the potential impacts of acoustic emissions associated with a shallow water surgeWEC in the high energy, nearshore environment at Camp Rilea. Due to delays and uncertainties in the planned RME SurgeWEC demonstration project a No-Go termination point was reached after the first budget period restricting the project to pre-installation baseline recordings.

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. Again, due to the lack of surgeWEC related construction and operational acoustic emissions, the full objectives of the study could not be met and results are limited to baseline recordings and development of the methodology for acoustic data collection and analysis.

METHODOLOGY

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). Placement of the lander frames for the first (spring) deployment was complicated by commercial crab fishing gear and therefore deployment locations for the landers were moved to a safe distance from the fishing equipment. The campaign style deployments occurred during spring, summer, and fall of 2016 to capture seasonal variation in ambient noise levels (Table 1).

The landers were deployed and recovered on a 4-6 week intervals based on vessel availability and weather and to avoid sanding in and sediment burial in the highly dynamic nearshore zone.

Table 1. Hydrophone lander deployment dates and locations for the spring, summer and fall off Camp Rilea in 2016.

Deployment	Dates	Lat (inshore)	Long (inshore)	Lat (offshore)	Long (offshore)
1	April 20 – May 29	46.1060 N	-123.9700 W	46.1111 N	-123.9719 W
2	Jun 30 – Aug 15	46.1100 N	-123.9640 W	46.1086 N	-123.9699 W
3	Sep 16 – Oct 10	46.1103 N	-123.9643 W	46.1089 N	-123.9698 W

Figure 1. The color coded deployments (D1 orange; D2 white; D3 red) and locations of the inshore (I) and offsore (O) hydrophone landers at Camp Rilea, OR in 2016. The proposed location of the RME surgeWEC is shown as a green triangle shoreward of the landers.

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 10 m depth contour was chosen as a shoreward deployment limit to reduce potential damage from breaking wave action and to avoid data contamination and burial rates encountered inside of the estimated sediment transport closure depth of 10-12 m found along the Pacific Northwest coast.

Each hydrophone lander frame was outfitted with 2 identical hydrophone sensors horizontally separated by a distance of 1 m. The use of dual sensors with 1 m separation was designed for coherence measurements to assist in quantifying periods and frequencies contaminated with wave induced flow noise. Unfortunately, without proper orientation of the hydrophones in a parallel sense to the approaching wave fronts, no compass orientation for the lander on the seafloor, and a relatively small spatial sensor separation, coherence measurements for wave induced flow noise at the low frequencies of interest was unsuccessful. Fortunately, flow noise contamination periods and affected frequencies could be identified in the spectral analysis detailed in the Results section below.

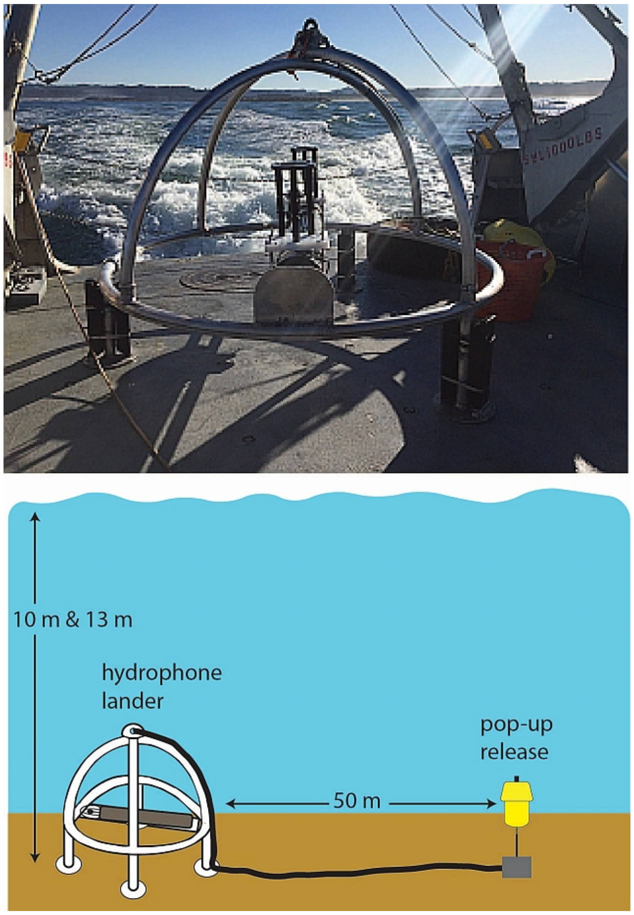

Figure 2. (Upper) A picture of the hydrophone mounted on the aluminum hydrophone lander frame prior to deployment

The hydrophone instruments are built “in-house” at the Oregon State University 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 (Fig. 3). 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 (Fig. 4). 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. A free drifting approach was used to avoid flow noise contamination of the recordings resulting from non-propagating acoustic fluctuations at the hydrophone fluid-sensor interface common to vessel tethered approaches. The drifter is designed to decouple surface wave motion from the hydrophone and has limited surface area above the waterline to reduce “sail” effects that cause the hydrophone system to move faster through the water than the mean current. This design therefore minimizes data contamination from flow noise generated by wind induced lateral movement of the hydrophone and/or vertical motion resulting from surface waves. The ADUH was deployed on 3 different days: July 1, August 16, and September 16 in 2016 using a variety of vessels. After ADUH was deployed, the support vessels were moved a significant distance away (at least 100 m) and shut down to drift with the instrumentation. Each drift consisted of up to 1 hour of continuous recording prior to recovery.

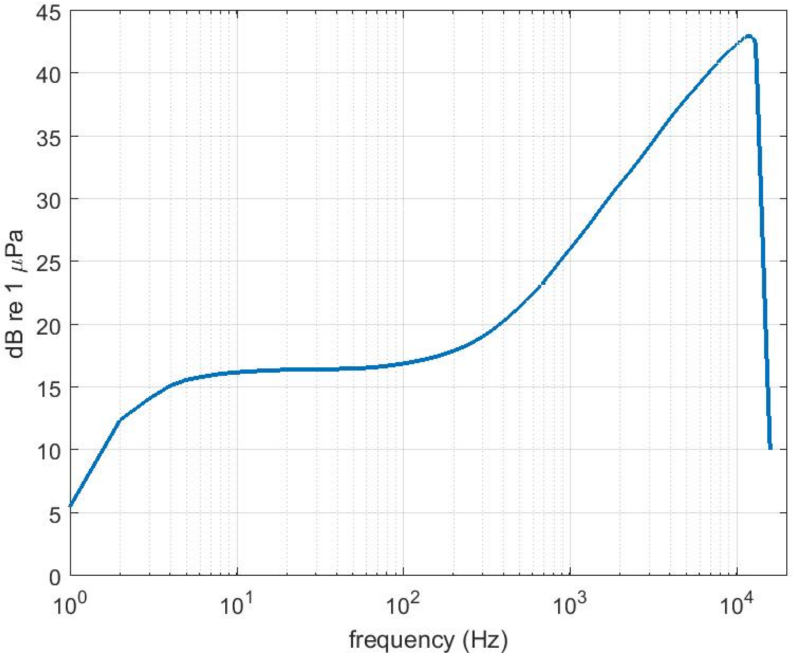

Figure 3. The instrument response curve for the hydrophone preamplifier.

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. SPLrms is calculated as:

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

with units reported in (dB re 1 µPa).

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 (10-13 m) create substantial flow noise contamination. For the initial spring deployment, lander hydrophones were outfitted with thin, nylon flow shields stretched over the frames supporting the sensors. Post recovery data analysis determined that these shields had a negative effect for reducing flow noise near the hydrophone sensors. In fact, they produced a slight flutter during periods of strong currents associated with peaks in wave orbital motions at these shallow depths and were subsequently removed from future deployments.

Spectral analyses of the fixed hydrophone data show frequencies from 500 Hz – 13 kHz provide reliable acoustic measurements void of flow noise contamination. The continuous acoustic data recordings from the summer and fall lander deployments enable robust temporal measurements of ambient noise levels in a variety of sea state conditions.

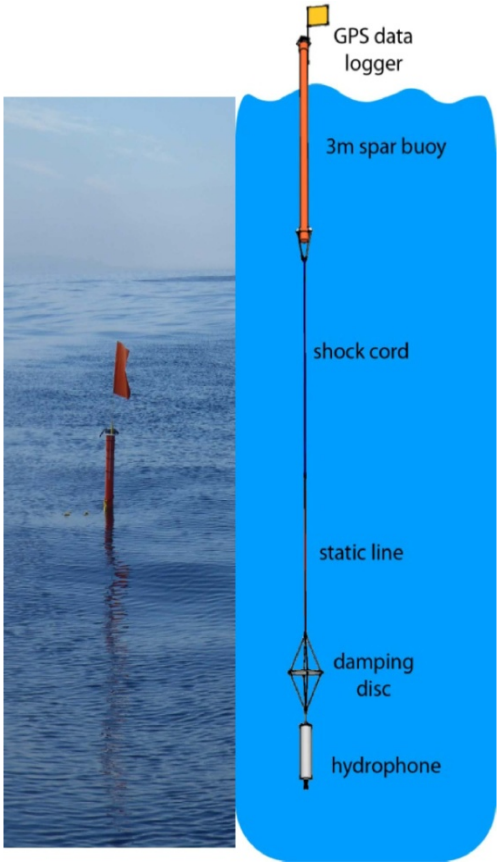

Figure 4. A picture of the deployed ADUH system (left) and schematic of (right).

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. Unfortunately, the low frequency acoustic energy generated by the shock impact that often accompanies the initial plunge 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 related to high velocity wave orbital motions. 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 at varying levels dependent on the incident wave energy making estimates of absolute, acoustic energy levels challenging. Spectrograms derived from hourly averages of acoustic recordings at the inshore (10 m) and offshore (13 m) stations during the summer deployment (July) show the strong influence of flow noise on spectral levels below 500 Hz (black dashed line; Fig. 5). Due to its shallower depth and closer proximity to the surf zone, the 10 m depth station experienced higher wideband energy levels compared to the deeper 13 m offshore 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). Spectral analysis for baseline acoustic conditions is therefore limited to frequencies above 500 Hz in order to avoid flow noise contamination and describe acoustic variability associated with surf and wind generated surface processes. From existing data on WEC recordings, MKH noise is likely to be generated in the lower frequency ranges from hundreds of Hz up to a couple of kHz (f < 2 kHz; Bassett et al., 2011; Tougaard, 2015; Polagye et al., 2017). Flow noise contamination in the lowest frequencies (f < 500 Hz) at the shallow depths of Camp Rilea (~ 10 m) makes absolute acoustic noise level measurements at these low frequencies challenging if not impossible from a fixed hydrophone station in higher energy conditions. Nevertheless a more qualitative characterization of low frequency (f < 500 Hz) WEC generated signals may still be achieved. For instance, a description of the frequency structure and modulation of an MHK signal as a function of wave period may still be useful for these lower frequencies even in the presence of flow noise, but an absolute noise level measurement (e.g. SPLrms, PSD) of the signal will be invalid due to confounding flow noise contributuions. Therefore, for our analysis in the absence of a WEC, quantifying the baseline ambient noise levels in the area was limited to frequencies unaffected by flow noise contamination (f< 500 Hz) over the duration of the project in order to provide robust and reliable characterization and measurement of the acoustic field at these frequencies. If the surgeWEC had been deployed, we would include time dependent spectral analysis of the full recorded bandwidth, identifying periods with flow noise affected frequencies to best characterize the WEC generated signals during particular low energy conditions. During calm conditions, measurements of WEC generated noise in lower frequencies recorded by the fixed hydrophones would likely be possible down to the tens of Hz and provide information on the types of sounds generated by the device that could also be compared with coincident drifting measurements.

As previously mentioned, earlier studies suggest MKH noise is likely to be generated in the lower frequency ranges from hundreds of Hz up to a couple of kHz placing the frequencies monitored in this study well within the range of concern for acoustic related ecological effects. We recognize some marine mammals found in the Camp Rilea area (e.g. harbor porpoise) utilize much higher frequencies (13 to ~140 kHz), but this acoustic range is not likely to be effected by potentially much lower WEC generated emissions. Since the focus of the study was on acoustic effects in WEC generated frequencies, we chose to limit the study to those frequencies bands likely to see the greatest impacts < 13 kHz. The lower frequencies where baleen whales and pinnipeds common to the area may be sensitive were well monitored using a 13 kHz cutoff. For future studies at Camp Rilea, we would recommend sampling the 10 Hz – 20 kHz frequency range (sample rate ≥ 44 kHz to avoid aliasing) to remain consistent with some of the early NMFS regulatory requirements for monitoring MHK devices (e.g. PMEC – SETS).

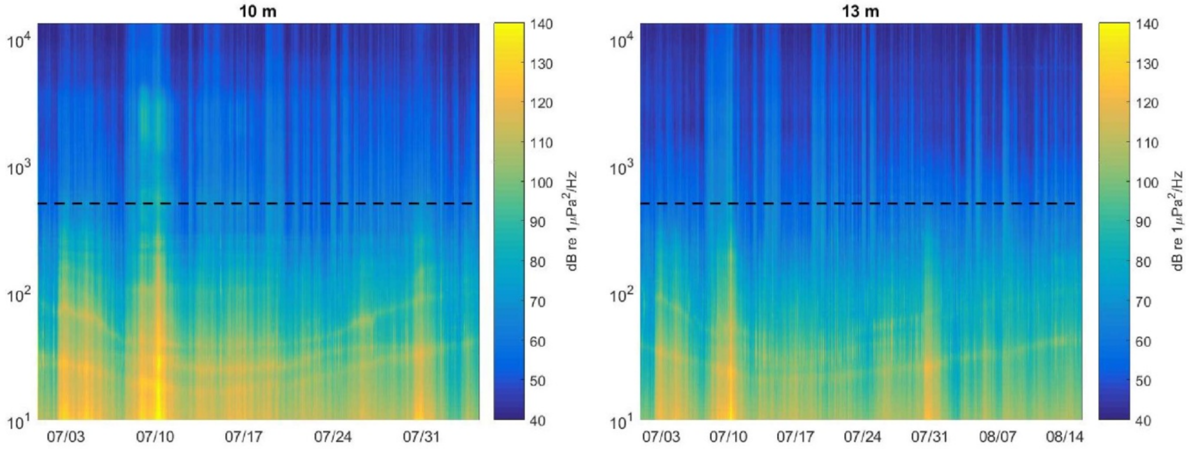

Figure 5. Spectrograms showing the hourly averaged, acoustic energy levels as a function of frequency and time for the 10 m and 13 m depth hydrophone lander stations during the summer deployment. The black dashed line indicates the 500 Hz frequency on the $\log_{10}$ vertical axis.

Nearby meteorological and wave climate measurements were used to investigate environmentally forced underwater noise level variability at the Camp Rilea hydrophone lander stations. The Scripps Institution of Oceanography's Waverider Buoy off Clatsop Spit (46243[1]) located 17 km west of the fixed hydrophones provided measurements of significant wave heights (H_s) and dominant periods (T_p). Similarly, wind speeds (wspd) from NOAA's National Ocean Service meteorological station at Astoria (AST03 94390[2]) located 18 km east-northeast of the hydrophone locations were used for comparisons of noise levels with surface wind conditions. Figure 6 shows comparisons of noise levels (500 Hz – 13 kHz) as a function of both H_s and T_p at each of the Camp Rilea hydrophone stations. Noise levels are binned and averaged according to 0.5 m steps in H_s ranging from 0.5 – 4.5 m and 1 second steps in T_p with a range 1-19 seconds. Bins without at least 2 hourly averaged acoustic observation values are removed from the analysis. Patterns in elevated noise levels show significant correspondence with rising H_s at both inshore and offshore stations. Meanwhile, during similar wave height conditions, increasing T_p 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. Comparisons of underwater noise levels (500 Hz – 13 kHz) with wind speed data (Fig. 7) suggest noise levels begin to rise after crossing a threshold of 3-4 m/s where stronger "whitecapping" or wind wave breaking may begin to occur. The distance inland (18 km) of the AST03 station introduces significant bias to this relationship where winds on the coast can be appreciably different than those from just a few km's inland. This relationship appears to be better reflected in the high amplitude (H_s), low period (T_p) influence of wind waves on the noise levels in Figure 6.

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[1] http://www.ndbc.noaa.gov/station_page.php?station=46243

[2] http://www.ndbc.noaa.gov/station_page.php?station=asto3

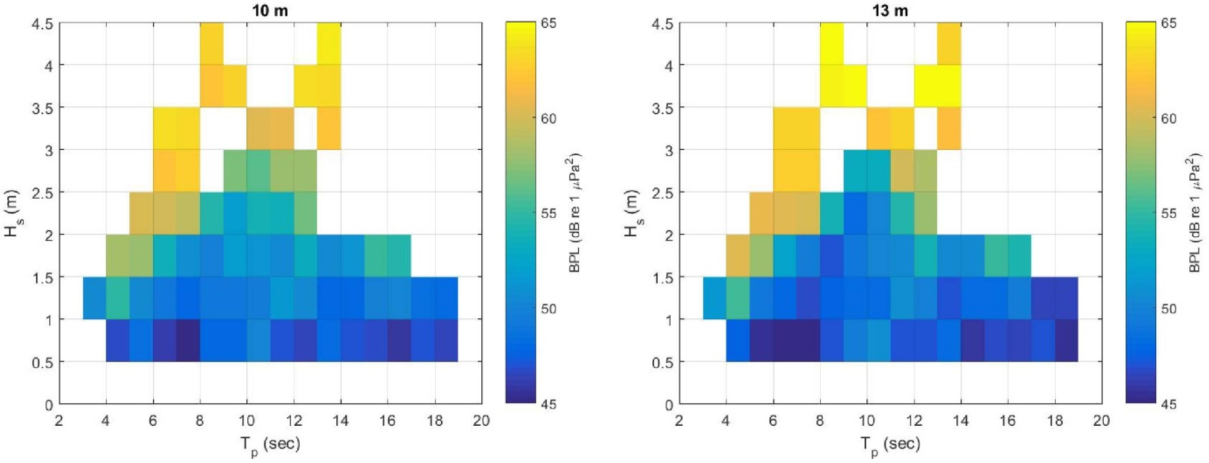

Figure 6. Underwater noise Band Pressure Levels (BPL; 500 Hz – 13 kHz) as a function of significant wave heights (Hs) and dominant wave periods (Tp) for inshore (10 m) and offshore (13 m) hydrophone stations.

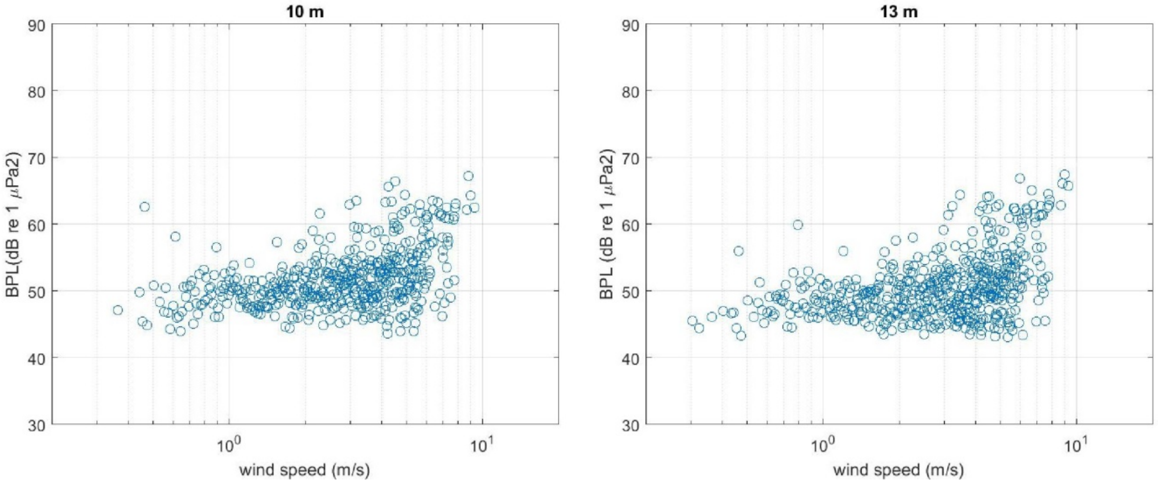

Figure 7. Comparisons of underwater noise Band Pressure Levels (BPL; 500 Hz - 13 kHz) averaged in 10 cm/s wind speed bins.

Percentile distributions of underwater spectral noise levels (Fig. 8) 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) SPL_{rms} calculated from 10 second data frames during summer and fall recordings show the consistently higher noise levels at the inshore verses offshore stations (Fig. 9). 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.

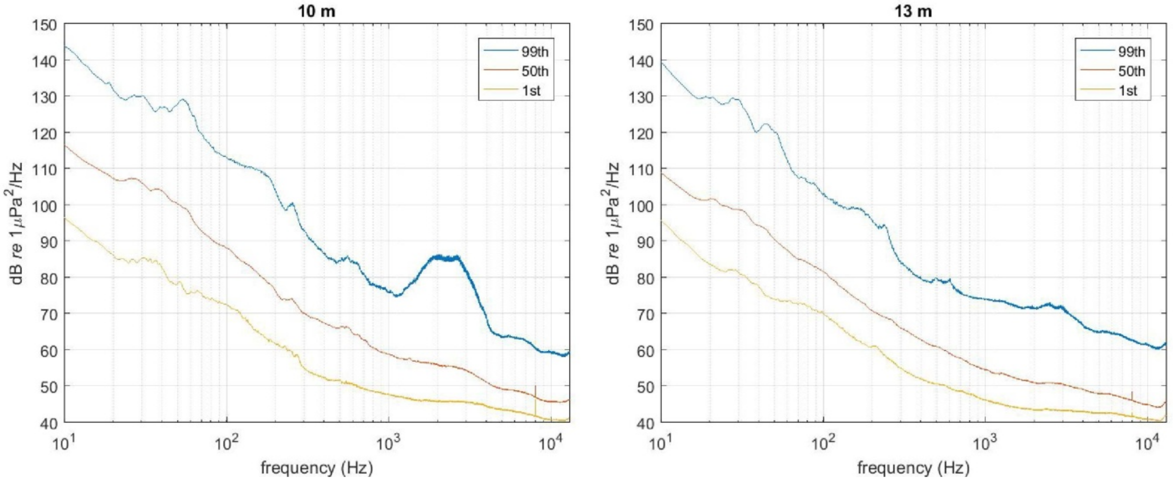

Figure 8. Frequency dependent percentile distributions (1st, 50th, 99th) of noise levels from hourly averages at the inshore (left) and offshore (right) hydrophone stations. 50th percentile curves represent "typical" acoustic conditions recorded at each station during summer and fall deployments.

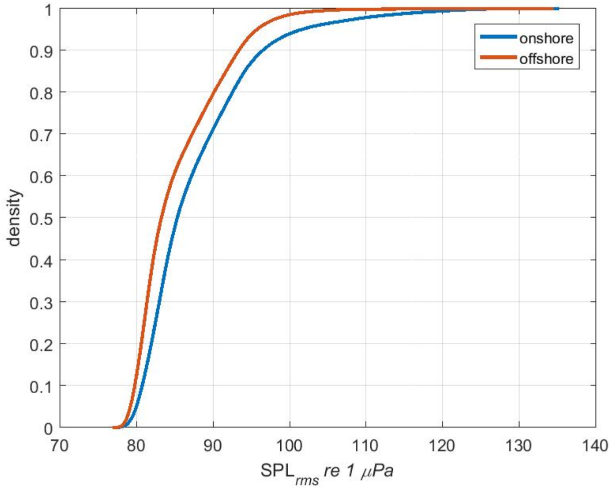

Figure 9. Empirical cumulative distribution functions of SPL_{rms} at the onshore and offshore hydrophone lander stations during the summer and fall deployments calculated from 10 second data windows and high passed at 500 Hz.

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 (Table 2). Spectral analysis reveals surf generated noise from nearby breaking waves in the surf zone is a dominant sound source in frequencies ranging from 1-9 kHz. Meanwhile, flow noise associated with wave motions appears to influence low frequency noise levels (f < 50 Hz) throughout the drifting recordings. The compliance of the drifting hydrophone system significantly reduces the affected frequency range (by an order of magnitude). The spatial distributions of root mean square sound pressure levels (SPL_{rms}) averaged over 30 second periods and high pass filtered with a corner frequency f_c = 50

Table 2. Acoustic Drifting Underwater Hydrophone (ADUH) deployment dates and measured environmental conditions.

Date	H_s (m)	T_p (sec)	wspd (m/s)
Jul 01	0.7	17	1
Aug 16	1.4	13	2
Sep 16	0.9	9	2.5

Hz to remove the influence of flow noise show variability largely associated with differences in vessel traffic that was visually observed from the support vessel during the drifts (Fig. 10). 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 (~ 1 hr). Fifteen minute spectral averages from representative periods during each drift show measurements reveal a range of noise levels despite calm and very similar environmental conditions (Fig. 11). This variability is attributed the acoustic differences in light to medium nearby vessel traffic experienced during the drifting recordings. Observed recreational and commercial fishing vessels were within an estimated range of 0.25-3 km from the drifter during recordings.

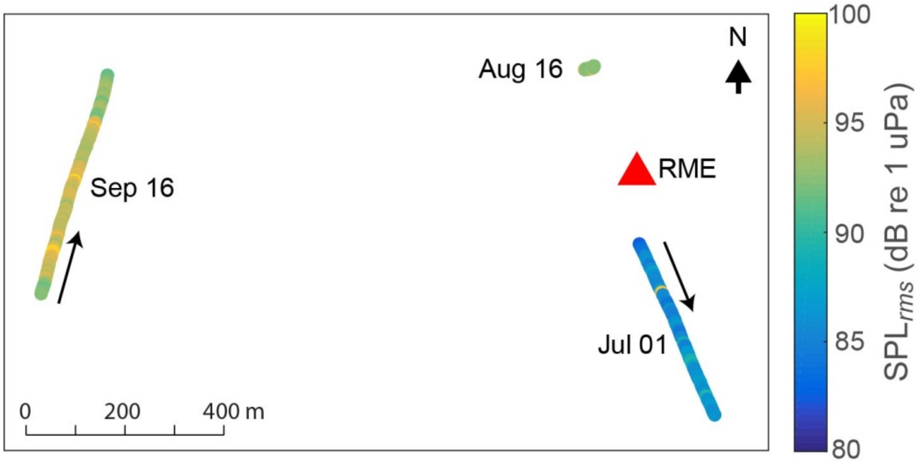

Figure 10. Map view of SPL$_{rms}$ calculated values from ADUH hydrophone drifter recordings collected over 3 different days in the summer and fall. The proposed location of the RME surgeWEC device is shown as a red triangle and direction of the drifts is shown by arrows. The Sep 16 drift was deployed ~1 km away from the RME position due to vessel traffic in the area.

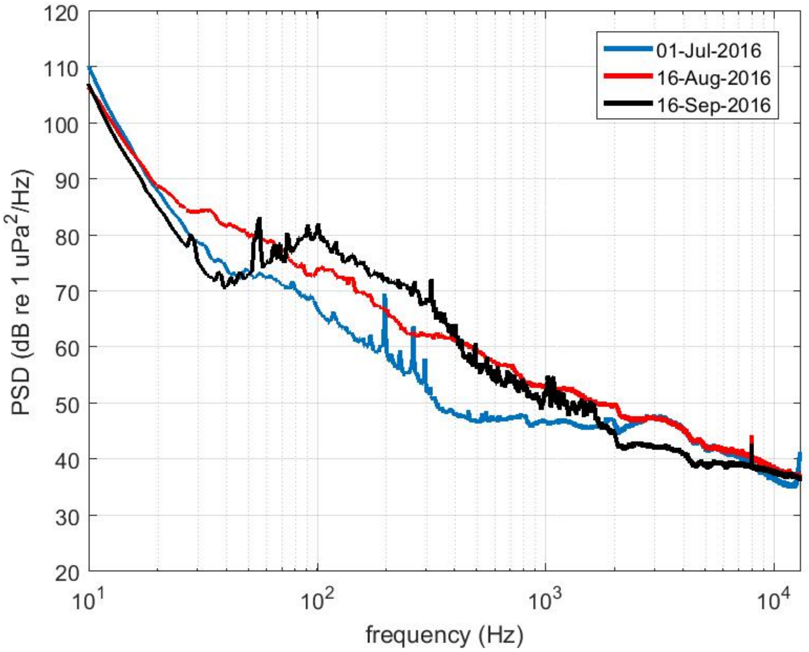

Figure 11. Fifteen minute spectral averages of representative periods from ADUH drifts.

CONCLUSIONS

Fixed and mobile acoustic recordings show the shallow waters of the nearshore region off Camp Rilea are dominated by the natural processes of breaking surf and wind wave generated sounds. Despite concerns that surf noise may saturate acoustic recordings in close proximity to the wave breaking zone, our results indicate that when using the instrumentation and approach presented here there is sufficient dynamic range to record and characterize surgeWEC generated acoustic emissions in the shallow waters off Camp Rilea, OR with a 16 bit hydrophone system. Flow noise is shown to be a confounding factor for acoustic energy in frequencies below 500 Hz during the range of environmental conditions presented here at fixed hydrophone receiver station depths of 10 – 13 m. Nevertheless, at a range of ~ 150 m, acoustic emissions from WECs in frequencies ranging from 500 Hz up to our system cutoff at 13 kHz can be recorded, identified and reliably quantified if they are of sufficient source level. During calmer conditions, surgeWEC signals should be characterized and measured for frequencies below 500 Hz during periods manually identified to be devoid of flow noise contamination. Previous acoustic recordings around deployed WECs (Polagye et al., 2017a; Polagye et al., *in review*) show similar low frequency limitations regarding flow noise contamination with fixed hydrophone recorders. For example, despite deeper water depths (30 m & 60 m) at the WETS facility which help to reduce wave orbital velocities and therefore affected flow noise frequencies compared to Camp Rilea (10 m), acoustic measurements from fixed hydrophones of low frequency WEC generated signals (hundreds of Hz) had to avoid periods of elevated flow noise linked with higher energy, longer period swell.

Polagye et al (*in review*) identify a low frequency flow noise contamination cutoff around 250 Hz for acoustic records collected during their study at WETS, yet can still identify acoustic emissions from the device at around 100 Hz.

The use of a mobile drifting hydrophone system during lower energy conditions reduces the influence of flow noise to frequencies below 50 Hz for range dependent comparisons and with coincident fixed station recordings of WEC noise. It is the combination of fixed station recorders for time and environmental condition dependent WEC measurements coupled with range dependent mobile platform recordings that provides the best temporal and spatial description of WEC generated signals.

In addition, local vessel noise was observed to make transient contributions to ambient noise levels and is not a consistent, dominant source of sound in the fixed station recordings. Similarly, acoustic contributions from marine mammal vocalizations to ambient levels were negligible.

The influence of wave breaking (both surf and wind waves) on ambient levels was shown to scale with incident wave amplitudes (H_s) without regard to increasing wave periods. Proximity to the surf zone was also an important factor where the inshore station experienced consistently higher acoustic energy levels as surface wave conditions increased. Less obvious was the connection between measured wind speeds and underwater noise levels. Although this is likely due the 18 km distance inland of the meteorological station which is not likely representative of conditions on the coast.

Our research presents some of the first long-term acoustic recordings in this challenging coastal area that will inform and assist future marine renewable energy projects in permitting, licensing and monitoring efforts by providing initial background noise levels and data collection techniques that begin to fill existing knowledge gaps and address concerns due to uncertainties surrounding shallow water coastal ambient noise levels in Oregon.

Estimated Costs:
1) Fixed seafloor hydrophone station: $35K ea (hydrophone instrument; frame and mooring line and hardware; pop-up recovery system).
2) Drifting hydrophone system: $25K ea (hydrophone instrument and spar with gps/ telemetry)
3) Vessel time: M/V Forerunner $2K/day for moorings; Drifter vessel support: $150/hr
4) Oregon Dept of State Lands Special Use License $1500/2 yr

Total estimated cost for fixed and mobile hydrophone platforms and hardware, vessel time and permits/licensing for 3 hydrophone deployment/recovery operations and 6 drifting data collection efforts is $111,500. This does not include personnel support costs including labor and travel.

Assessment of Methodology

Limitations:
The energetic shallow water environment at Camp Rilea introduces significant challenges for fixed hydrophone stations including flow noise from wave orbital motions, burial from high sediment transport rates, and commercial and recreational fishing activity. The flow noise contamination in low frequencies ($f < 500$ Hz) is severe during periods of elevated wave heights and wave periods causing limitations to the accurate measurement of noise levels in a substantial range of WEC generated acoustic frequencies. A possible mitigation strategy for wave orbital flow noise, could involve "mooring" the hydrophone sensor by suspending it from the seafloor with floatation attached by a compliant tether. In this way, the sensor would be able to move more freely with wave orbitals, thus reducing the velocity, turbulence, and non-acoustic pressure fluctuations at the sensor/seawater interface.

The high turn-around rate of the fixed instrumentation to keep it from sanding in and being buried in the nearshore zone could also be viewed as a limitation. Similarly, due to the significant expansion of the surf zone in winter, recordings from the highest wave height and wave periods during these conditions are not recommended with a high probability of loss or decreased survival of the equipment in the breaking surf zone.

Strengths:
The hydrophone lander approach provides robust temporal estimates of changing sound levels and frequency content with ocean conditions. Despite, flow noise contamination during periods of elevated energy, WEC generated signals can be measured and characterized at frequencies above 500 Hz and identified and described at lower frequencies (< 500 Hz) less their contribution to absolute levels.

Drifting measurements provide important range dependent information on WEC generated signals and lower flow noise contamination frequencies to below 50 Hz. Using a drifting hydrophone near the WEC and another control drifter ~ 1.5 km in the area during times void of vessel traffic would provide valuable means for quickly assessing the acoustic contribution of WEC generated signals to ambient noise levels.

LESSONS LEARNED AND RECOMMENDATIONS

1) With the implementation of Oregon's Territorial Sea Plan, scientific projects that plan to deploy equipment on the sea floor within the state's territorial waters (< 3 nm) for an extended period of months/ years are required to apply for a Special Use License with the Oregon Department of State Lands (DSL). After submission, DSL leads the approval process sharing application materials with various agencies including U.S. Army Corps of Engineers, U.S. Coast Guard, Oregon Dept. of Fish and Wildlife and Oregon Department of Land Conservation and Development who all have the chance to weigh in with comments, problems with the project and approval. An approval signature is required in the DSL application from the authorized Coastal Zone Management agent at the county level where the project will occur. The project application then must go through a 30 day public comment period where any

concerned citizen, agency or conservation group may submit materials challenging the request. Applicants are required to respond in written format to any submissions made during the comment period to DSL. For instance, for this project at Camp Rilea we were required to document with the state archeologist that to the best of our knowledge, we were not working around any historical shipwrecks and if we encountered any during the project we would cease and desist all operations and report to DSL. Additionally, DSL requires a bond to insure that if the project defaults for any reason, the state is financially covered to recover all equipment left on the seafloor. This bond can represent a significant cost to the project, but in our case Oregon State University's liability insurance was sufficient for DSL approval. The entire license application and approval process can take upwards of 6 months or more dependent on the level of complexity and costs around $1500 for a 2 year license.

2) Offshore operations at Camp Rilea require significant planning and coordination with military personnel to ensure safety and confirm the live fire range is inactive during offshore work times. Up to a week in advance, a call to Range Control is necessary to inquire their schedule for live fire training exercises on the range. You will need to clear times with the Range Control scheduling officer via email or by phone in order to occupy the waters offshore of the range in advance. The morning of offshore operations call Range Control and give them your vessel name and an estimated time for arrival on station. When you arrive at the northern boundary of the Camp Rilea range, initiate a Channel 16 radio call from your support vessel to "Camp Rilea Range Control" and ask for permission to proceed to the work station. Give them an estimated time on station and let them know you are monitoring Channel 16. After work is finished, initiate a call to Range Control again on Channel 16 and let them know you are departing the controlled area.

Camp Rilea Range Control: (503) 836-4096/4052
Leidos liason: Rick Williams (503) 484-4415

3) The Columbia River bar crossing is one of the most dangerous port of entry/exits in the world due to the combination of the large volume of water moving through the channel on each tidal exchange and the higher wave climate of the Pacific Northwest. Tidal currents are very strong causing dangerous conditions during ebb flows. Crossings should be timed as best possible around flood tides. This significantly reduces the possible windows for offshore work and limits working hours on station. Additionally, if you are transiting from Astoria plan for several hours (~ 3) of transit time to and from Camp Rilea due to tidal currents in the Columbia River.

Vessel support contacts
M/V Forerunner – Clatsop Community College – (503) 325-7962
Capt. Bill Wechter – Coastal Towing – (503) 298-0528

4) Although winter deployments of the hydrophone landers were not performed during this project, caution is suggested for future studies during winter conditions as the elevated wave heights and low sloping nature of the beach at Camp Rilea result in a significant expansion of the surf zone. The lander deployment positions in the spring/ summer/ and fall from this study

would have been well within the expanded winter surf zone, likely resulting in significant damage or equipment loss due to wave breaking induced turbulence and sediment burial. It is therefore our recommendation winter deployments of fixed hydrophone stations are avoided and substituted instead with drifting recordings when environmental conditions allow.

5) Differing levels of bio-fouling of the aluminum frame, pop-up release and hydrophone instrumentation occurred during each deployment. Bio-fouling during the summer deployment was exceptionally bad with up to 3 inches of barnacle growth on all surfaces. We recommend applying bio-fouling paint or removable tape to surfaces where growth is undesired or difficult to clean off. This also has strong implications for WEC deployments in the Camp Rilea area where summer months will experience substantial biological growth without proper mitigation.

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