ACOUSTIC CHARACTERISTICS OF TWO POINT-ABSORBING WAVE ENERGY CONVERTERS

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INTRODUCTION

Large-scale deployment of wave energy converter arrays will be necessary if wave energy is to meaningfully contribute to global energy supplies. Further, there are many competing wave energy converter (WEC) designs, with no clear trend towards design convergence. This motivates two environmentally-focused questions on the sound produced as a byproduct of WEC operation. First, where should the sound produced by wave energy conversion be placed in the context of other natural and anthropogenic sound? Second, do aspects of WEC design substantially affect the sound produced? Studies to date (summarized in [1]) have largely concluded that individual WECs are unlikely to have significant environmental effects, but these have often been snapshots during a single operational state or a limited number of sea states. Further, each has used somewhat different methods of study, complicating comparisons.

METHODS

Here, we present acoustic measurements of two types of point-absorbing wave energy converters with both spatial and temporal characterizations. Both devices have maximum electrical power outputs less than 30 kW, which is relatively small compared to utility-scale units.

Study Location

Measurements were obtained at the US Navy Wave Energy Test Site (WETS) in Kaneohe, HI. The wave climate, characterized by a Waverider buoy [2], has a dominant energy period of ~7 s.

Wave Energy Converters

The two WECs are the Northwest Energy Innovations Azura and Fred. Olsen Lifesaver. Both are defined as point-absorbers and their location within the test site is shown in Figure 1.

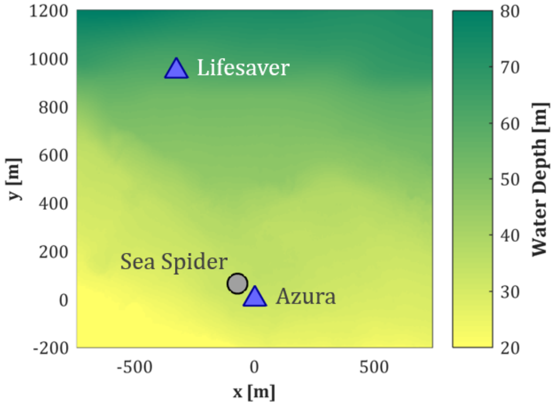

FIGURE 1. LAYOUT OF WECS AND INSTRUMENTS AT WETS. COORDINATES REFERENCED TO AZURA.

NWEI Azura

This WEC consists of a semi-submerged float that pivots between a pair of rigid, vertical spars. Relative rotary motion of the float is converted to electricity by means of a hydraulic generator positioned below waterline. The Azura was moored in 30 m of water and operated from June 2015 – December 2016.

Fred. Olsen Lifesaver

This WEC consists of a semi-submerged toroidal float (16 m outer diameter) with a relatively shallow draft (0.5 m). Power take off consists of up to five topside rotary generators, each of which is connected to a winch line that extends from the toroid to a fixed mooring point. Wave-induced toroid motion produces extension and retraction of these lines, yielding electrical power. The Lifesaver is moored in 60 m of water and has been operating since March 2016.

Acoustic Measurements

Acoustic measurements involve a combination of stationary observations to resolve long-term temporal trends and drifting measurements to identify specific contributions of WEC sounds, as well as evaluate spatial trends.

Stationary Measurements

Stationary measurements are obtained from DSG-ST (Loggerhead Instruments) recording hydrophones deployed on Sea Spider platforms (Oceanscience), which positions the piezoelectric element 0.9 m above the seabed. Hydrophones are deployed in pairs and are configured on staggered duty cycles (30 minutes of recording every 90 minutes) to extend deployment time and to provide redundancy should one hydrophone fail during deployment. Results here are presented for a single Sea Spider deployment at 100 m range from the Azura. The first Sea Spider deployment around the Fred. Olsen Lifesaver is currently underway.

Drifting Measurements

Drifting measurements are obtained from icListen HF (Ocean Sonics) hydrophones that record continuously at a rate of at least 256 kHz. This nominally resolves frequencies between 10 Hz and 100 kHz. However, flow-noise (i.e., pseudo-sound produced by differential movement between the hydrophone and surrounding water) and self-noise (i.e., propagating noise produced by the motion of the package) contaminate measurements below 200 Hz. These hydrophones are coupled, via a rigid spar, to a drifting instrumentation package adapted from the SWIFT drifter [3]. The hydrophone depth is nominally 1.2 m below the surface. In addition to the hydrophone, the package includes a GPS tracker (QStarz BT-Q1000eX), inertial measurement unit (Lowell Instruments MAT-1), and meteorological station (Airmar WX-200).

Data Processing

Acoustic data are processed using a fast Fourier transform and presented as pressure spectral densities (dB re 1μPa^2/Hz) or integrated across multiple frequencies as a band level (dB re 1μPa). For drifting measurements around the Azura, an *ad hoc* routine automatically identifies and "quarantines" samples significantly contaminated by self-noise and flow-noise characteristics. The algorithm compares instantaneous band levels that are similar when self-noise or flow-noise is present, but differ substantially in uncontaminated measurements. Stationary hydrophone data are manually reviewed to identify 10 samples (each 10 seconds in duration) without obvious contamination by anthropogenic or biological noise for combinations of significant wave height and energy period. Identification of WEC-specific sound uses a comparison between drifting observations at close range and at a distance beyond the probable acoustic range. A number of factors inhibit a direct comparison to an acoustic baseline [4].

RESULTS

A brief discussion of ambient noise at WETS is followed by a discussion of sound produced by each WEC.

Ambient Noise at WETS

At frequencies less than 1 kHz ambient noise is dominated by the sound from wind and waves [5]. At frequencies greater than 1 kHz, snapping shrimp dominate [6]. Seasonally, humpback whales produce vocalizations that dominate in the range of 100 Hz to 1 kHz. Several anthropogenic sources are also present. The most persistent is chain noise from the moorings used at the Lifesaver site and one unoccupied berth in deeper water. This sound is most intense around 1.5 kHz and is likely produced by chain motion from moorings that are not fully tensioned (as occurs when a berth is unoccupied). Military aircraft traffic periodically contributes tonal sound around 100 Hz and vessel traffic periodically produces broadband, high-intensity sound that masks all other ambient noise when vessel range is less than a few hundred meters.

NWEI Azura

Figure 2 shows an annotated periodogram of drifting measurements at close range to the Azura relative to a more distant reference position. A spectrogram of a similar drift is shown in Figure 6. Auditory review of these data suggests that the primary mechanism for sound production is the hydraulic generator, with secondary production from wave interaction with the spars and float. Consequently, we can conclude the Azura primarily produces sound at frequencies less than 5 kHz. Figure 3 shows the long-term temporal characteristics of Azura sound in the frequency band from 200 Hz – 1450 Hz (excluding frequencies affected by flow-noise during long-period swell and those dominated by non-WEC chain noise). Drifting measurements taken intermittently at similar sea states over this time period suggest limited long-term variability (i.e., the observed trends are unlikely a consequence of changes in the sound produced by the Azura). These results suggests only a modest variation in sound with sea state, some or all of which might be explained by increases in natural wave noise with sea state. Figure 4 shows the spatial variability of Azura sound in the same frequency band. These results suggest that, at a depth of 1.2 m, received levels are relatively omnidirectional, with only modest directivity to the upstream side of the WEC.

Fred. Olsen Lifesaver

Figure 5 shows a periodogram with specific events during a 30-second drift at a range of 30 m from the Lifesaver in January 2017. An annotated spectrogram of this drift is shown in Figure 6. Sound in the vicinity of the Lifesaver is a combination of multiple sources. During this drift, two of the Lifesaver's three power take-offs were in operation. One was operating normally (annotated as 'PTO') and produced a low-pitched sweep primarily below 600 Hz. The other PTO had a damaged bearing ('bearing') that produced a tonal warble centered around 750 Hz. In addition to these sounds originating from the WEC, distant chain noise originating from the unoccupied berth at 80 m depth was present, as was a metallic rattle ('rattle') and metallic impulse ('impulse') associated with the permanent moorings used to secure WECs at this berth. The latter two sounds are broadband, extending up to 55 kHz for the rattle and beyond 200 kHz for the impulse.

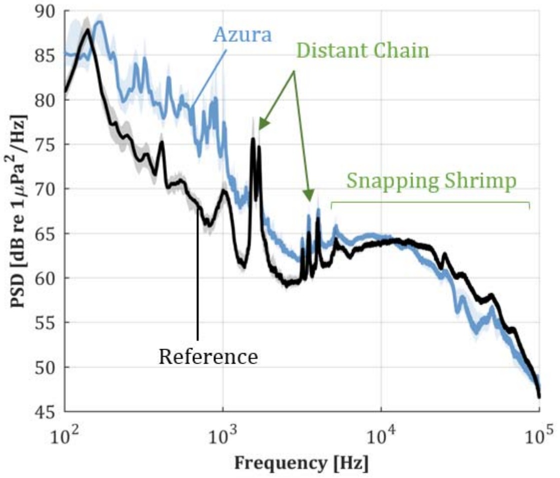

FIGURE 2. PERIODOGRAM OF DRIFTING MEASUREMENTS AT RANGES OF 10-20 M FROM AZURA.

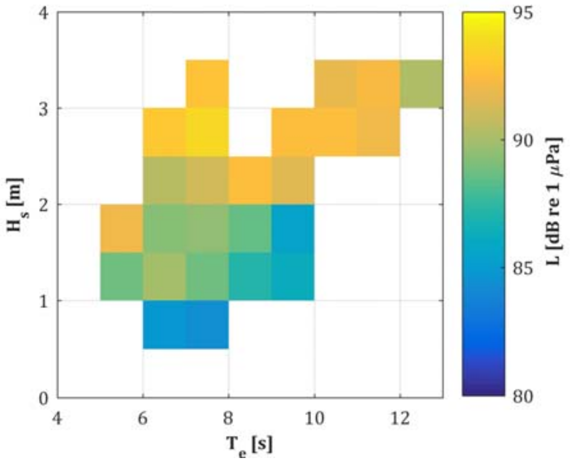

FIGURE 3. LONG-TERM TEMPORAL VARIABILITY OF AZURA SOUND.

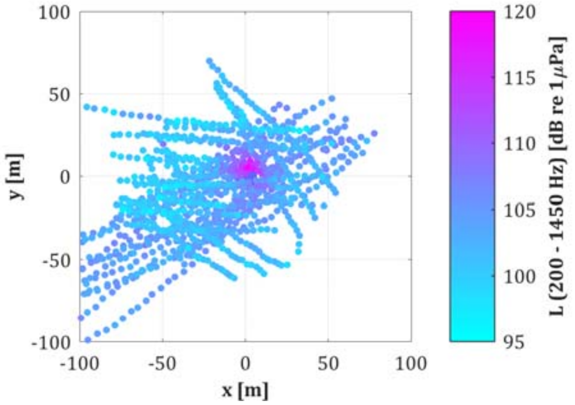

FIGURE 4. SPATIAL VARIABILITY IN AZURA SOUND (HS = 2.1-2.3 M). DRIFTS REFERENCED TO THE AZURA.

DISCUSSION

As expected from prior studies of WECs, the sound from individual converters of this scale is of limited environmental consequence, with the intensity and frequencies of sound well below those produced by recreational watercraft [9] at a range of several hundred meters. Each WEC does, however, produce sound that could be of environmental consequence if designs are scaled up and deployed in a large array. The Azura's subsurface, hydraulic power take-off produces a series of tones in the decade between 100 Hz and 1 kHz. These are functionally similar to humpback whale vocalizations (and difficult to distinguish when both are present in recordings). Consequently, the primary sound production mechanism from the Azura overlaps with the primary communication frequencies for these whales and could, *at sufficiently large scale*, require low-frequency cetaceans to increase their vocalization intensities to compensate (with possible energetic consequences) [7]. The Lifesaver power take-off, located above the surface,

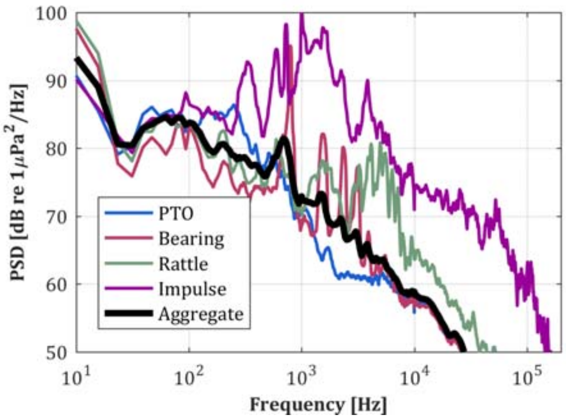

FIGURE 5. PERIODOGRAM OF DRIFTING MEASUREMENTS AT 34 M RANGE FROM LIFESAVER. ALL SPECTRA ARE MEDIAN VALUES FOR EACH TYPE OF EPISODIC EVENT.

is also hydraulic and produces sound over a similar range of frequencies when in normal operation, but with fewer tonal features. This is consistent with prior observations of this WEC [8]. Abnormal operation of a power take-off, here associated with a damaged bearing, produces higher frequency tonal sound and reinforces the benefit of integrating passive acoustics into condition health monitoring. It must be emphasized, however, that any effects of WEC sound are likely only to occur in relatively close proximity to an array (i.e., within a kilometer), given that source levels for individual converters, even at larger scale, are unlikely to approach those of ocean-going vessels [4].

While emphasis is generally placed on acoustic emissions from wave energy converters, the permanent moorings at the 60 m and 80 m berths at WETS currently produce episodic, broadband noise. As for the damaged bearing, this indicative of abnormal mooring condition (damage to sinker weights on mooring chain observed as a consequence of repeated contact). This observation highlights the value of a systems engineering approach to design acoustically unobtrusive WECs.

CONCLUSIONS

A combination of drifting and stationary measurements has been used to acoustically characterize a pair of wave energy converters. While the sound from neither converter rises to the level of environmental significance, results suggest that design choices, particularly in regard to location of the power take-off can have an effect on acoustic signatures.

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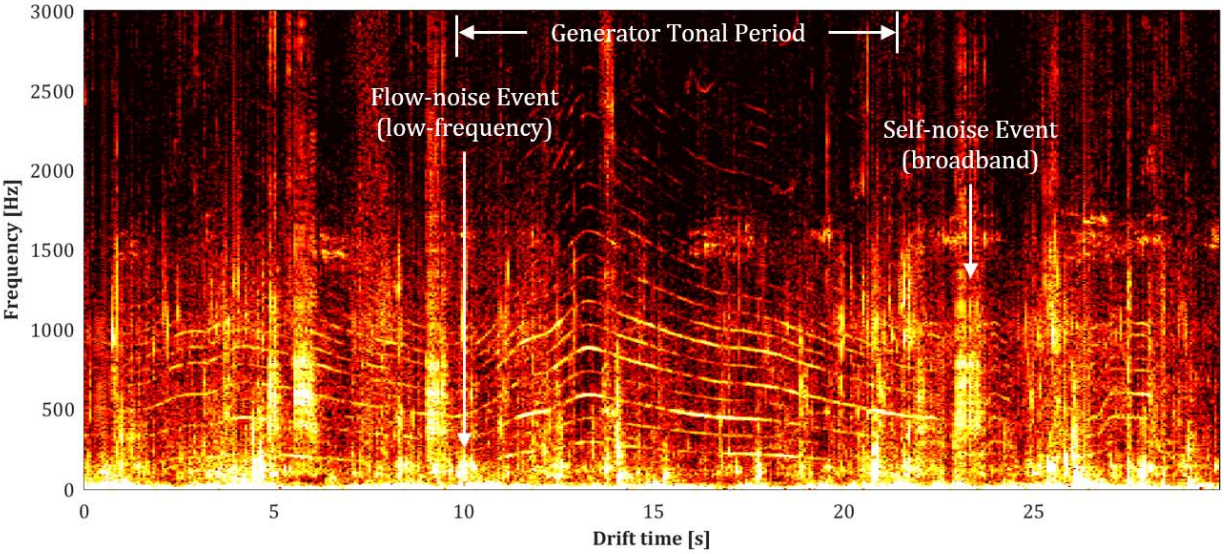

FIGURE 6. ANNOTATED SPECTROGRAM OF DRIFTING MEASUREMENTS AT RANGE OF 14 M FROM AZURA WEC.

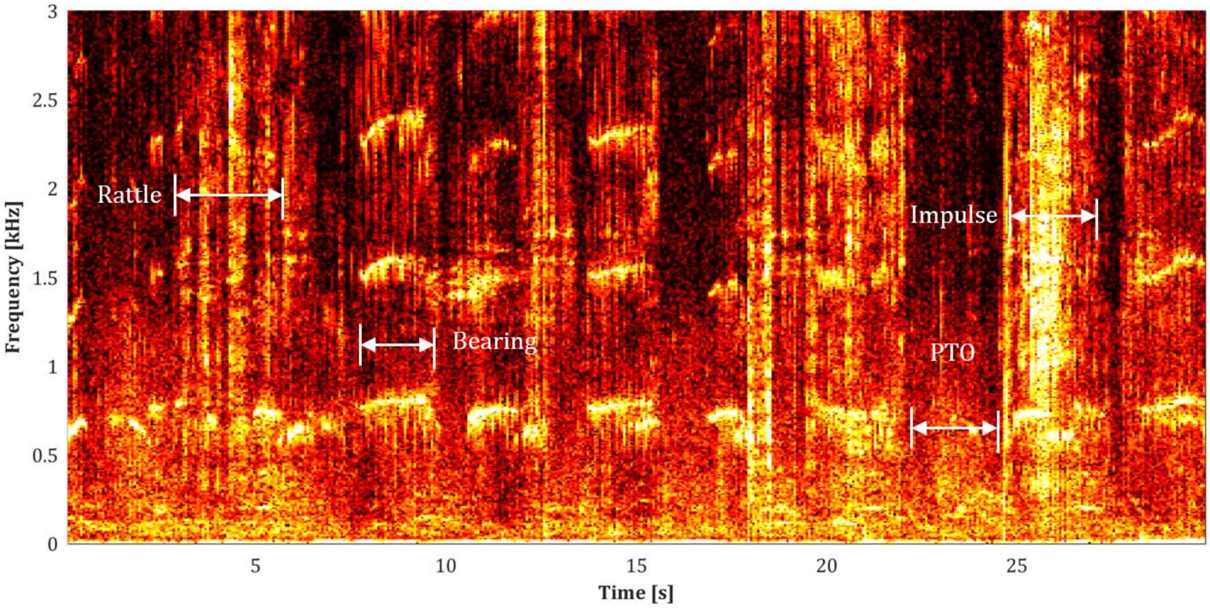

FIGURE 7. ANNOTATED SPECTROGRAM OF DRIFTING MEASUREMENTS AT RANGE OF 52 M FROM LIFESAVER WEC.