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Task 4: Environmental Impact Monitoring at WETS

WETS Acoustic Survey Final Report

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WETS Acoustic Survey Final Report

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1 Introduction

This report summarizes acoustic surveys undertaken by the University of Washington at the US Navy Wave Energy Test Site (WETS) from 2015 – 2019. WETS is located in Kaneohe, HI on the windward side of the island of Oahu and is within the restricted waters surrounding Marine Corps Base Hawai'i. WETS is a grid-connected wave energy test site with test berths located in 30 m, 60 m, and 80 m water depth. The seabed in the area is predominantly bedrock, in some places overlaid with a thin layer of sand. At the 60 m and 80 m berths, there are permanent moorings for wave energy converters (WECs) under test. These consist of surface floats that are connected to WECs and placed under tension by hawser lines, forming a three-point catenary mooring. A similar arrangement exists at the 30 m site, though the floats are sub-surface.

Over the five years of observations, two wave energy converters were deployed. The first, the Azura by Northwest Energy Innovations, occupied the 30 m berth during two distinct periods. Between these periods, the WEC was altered to improve its power capture. The more detailed survey reports referenced in this document refer to the initial configuration as 'Azura' and the altered configuration as 'Azura 2.0' to distinguish between these configurations. The second WEC, the BOLT-class Lifesaver by Fred. Olsen, initially occupied the 60 m berth, then was redeployed to the 30 m berth for a second round of testing.

Acoustic surveys utilized two types of instrumentation packages: fixed and drifting. The fixed packages (Sea Spiders) were deployed on the seabed for multi-month duration and their hydrophones were configured to record on a duty cycle. The drifting packages (DAISYs) were deployed from surface vessels for short-term observations, typically on the order of a few hours. These modes of observation provided distinct information. Fixed packages allowed for the study of temporally varying characteristics over long periods, while drifting packages allowed for observation of spatial characteristics. Data from fixed and drifting platforms were also utilized in a complementary manner. Drifting surveys rapidly identified the frequency range of acoustic emissions from a WEC. With this information, the recording frequency on the fixed hydrophones could be restricted to the range of interest for WEC emissions, increasing the allowable duty cycle and, consequently, the opportunity for observations in a wider range of sea states.

This remainder of this report is organized into five sections:

- A summary of Sea Spider deployments and lessons learned, including an index of underlying reports;
- A summary of DAISY drifts and technology development, also including an index of underlying reports;
- A short discussion of the soundscape at WETS and the contributions of WECs to this soundscape;
- The impact of these surveys on the understanding of acoustic emissions of WECs; and
- Next steps for data collection and instrumentation development.

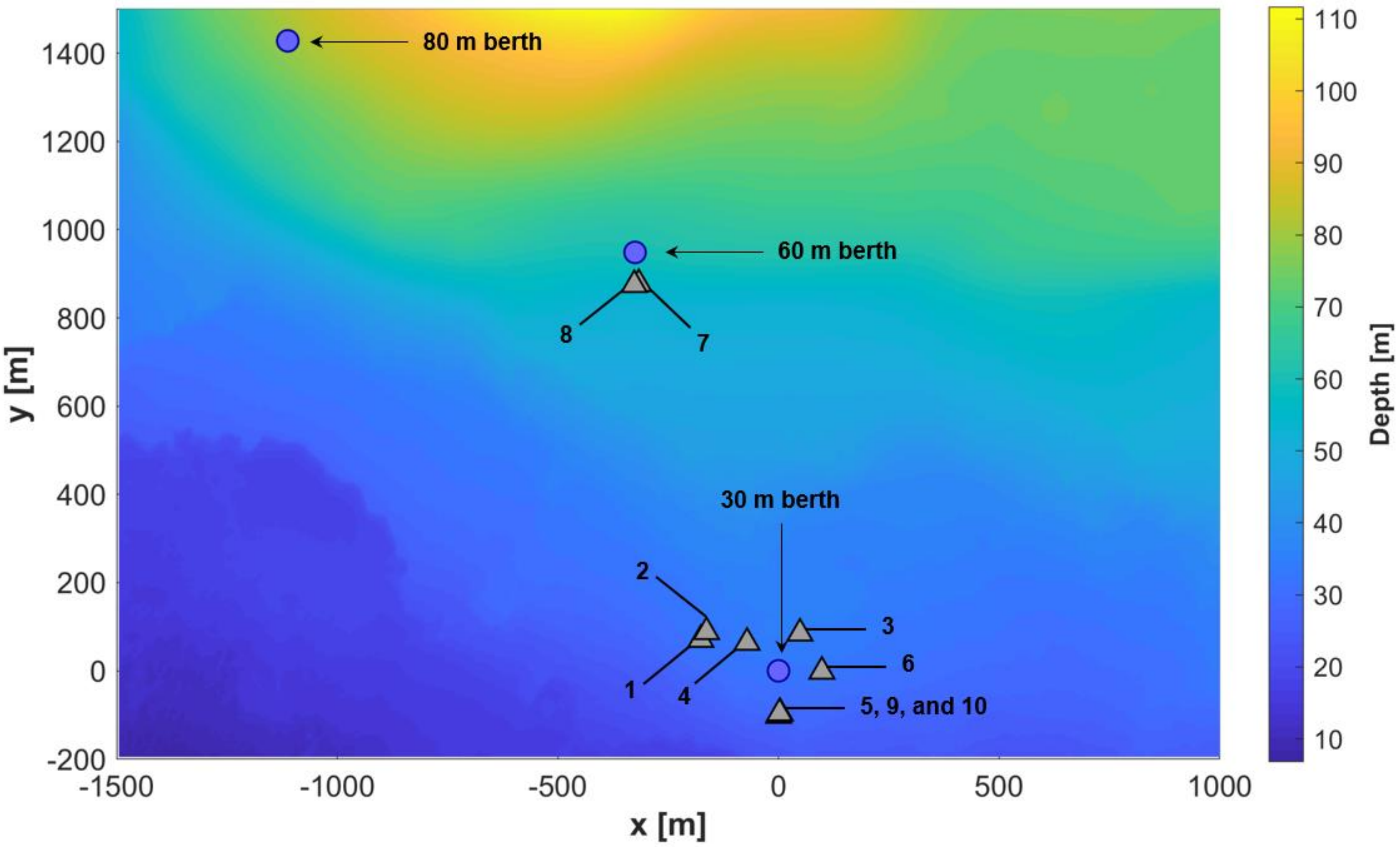


Figure 1: Sea Spider deployments at WETS (2015 – 2019)

2 Sea Spider Deployments

Sea Spider platforms equipped with Loggerhead DSG-ST (Loggerhead Instruments) were primarily used to record underwater noise over multi-month durations at fixed locations. Figure 1 shows the deployment location for each Sea Spider, Figure 2 shows a Sea Spider deployed on the seabed at the 30 m berth, and Table 1 summarizes deployment data and references to any descriptive reports.

Table 1: Sea Spider deployment summary and report references (2015 – 2019)

ID	Deployment	Recovery	Observations	Report
1	March 24, 2015	March 26, 2015	Azura	Sea Spider Report #1 (*no acoustic analysis*)
2	March 26, 2015	June 26, 2015	Azura	Sea Spider Report #2 (*no acoustic analysis*)
3	July 6, 2015	October 14, 2015	Azura	No report
4	July 8, 2015	October 14, 2015	Azura	No report
5	January 16, 2016	August 3, 2016	Azura	Sea Spider Report #4
6	January 16, 2016	N/A	Azura	No report: Sea Spider never recovered
7	December 6, 2016	March 8, 2017	Lifesaver (60 m)	Sea Spider Report #3
8	April 14, 2017	September 1, 2017	Lifesaver (60 m)	Sea Spider Report #1 (*DOD deliverable*)
9	December 18, 2017	March 26, 2018	Azura 2.0	Sea Spider Report #5
10	November 29, 2018	March 27, 2019	Lifesaver (30 m)	Sea Spider Report #6

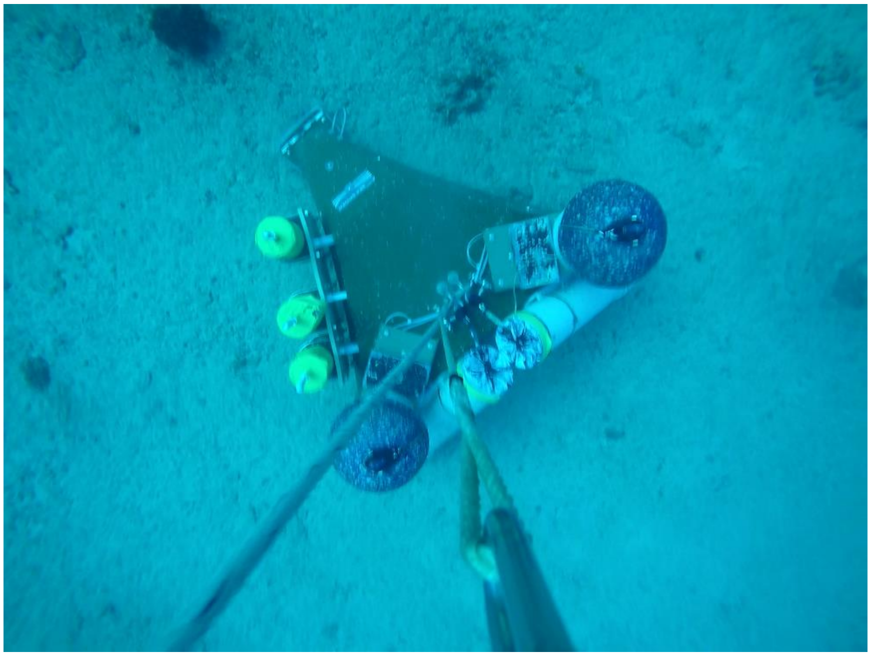


Figure 2: Sea Spider deployed on seabed at 30 m berth (credit: Patrick Anderson, Sea Engineering)

The data from the Sea Spiders was used to investigate the sea state dependence of sound originating from WECs and their moorings and to characterize the temporal evolution of the soundscape at each berth. The latter proved critical in correcting the misidentification of noise from damaged moorings as originating from a damaged bearing on the Lifesaver.

The Sea Spider deployments also encountered a number of challenges:

- During several deployments, particularly earlier in the survey, Loggerhead hydrophones did not deploy correctly, shutting down after only a few days of operation. This was eventually corrected by replacing the SD cards.
- While deployed in relatively deep water with limited tidal currents, wave orbital velocities were sufficient to periodically generate flow-noise that masked propagating sound at frequencies up to several hundred Hz. This was a greater challenge for Sea Spiders deployed at the 30 m berth, but also apparent in data from the 60 m berth.
- The amplitude of wave orbital velocities was not well-understood during early deployments. This led to the loss of one Sea Spider platform due to under-ballasting.
- At frequencies below 40 Hz, relatively high-amplitude, persistent sound was often observed in recordings. It remains unclear whether this is propagating sound or an artifact of reduced hydrophone sensitivity at low frequency.
- Recordings with a sample rate of 48 kHz contained a 3 Hz pulse at frequencies up to 100 Hz. The source of this signal is unknown, but is not present in recordings at 96 kHz and, therefore, likely a recording artifact.
- Due to the mooring spreads at the berths, the minimum safe deployment stand-off distance was on the order of 100 m, but propagating sound from the WECs was often only marginally observable at this distance.

An example spectrogram containing tonal PTO sound originating with the Azura, mooring sound ("chain rattle") originating from the 60 m berth, and flow noise, is presented in Figure 3. An example spectrogram containing the persistent low frequency sound and the 3 Hz pulse are presented in Figure 4.

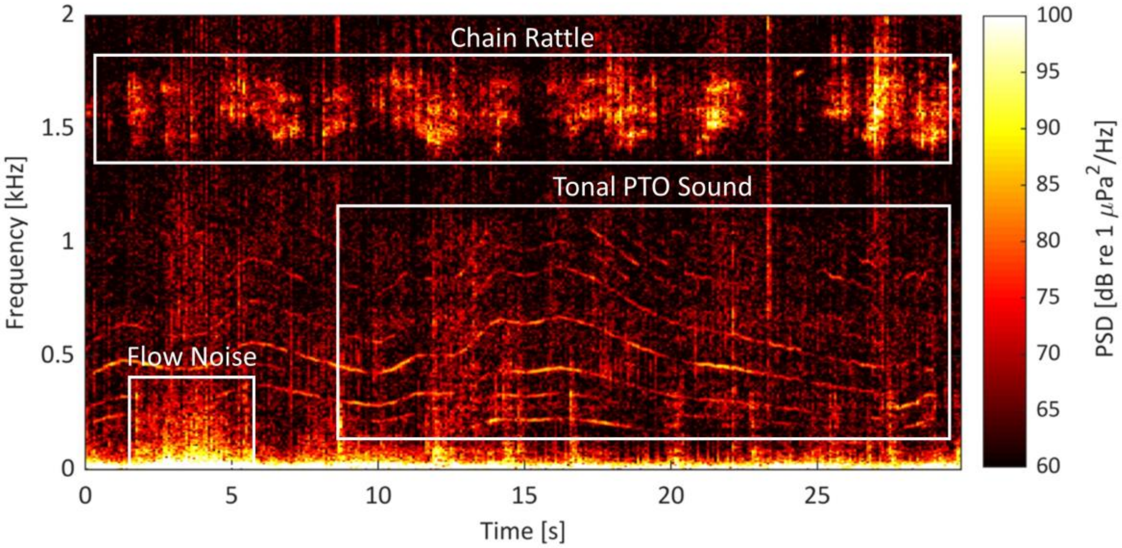


Figure 3: Example spectra containing tonal PTO generated sound (Azura), moring sound (chain rattle, 60 m berth), and flow noise.

T_e = 12.6 s, H_{m0} = 4.0 m, February 23, 2016, 07:14 UTC.

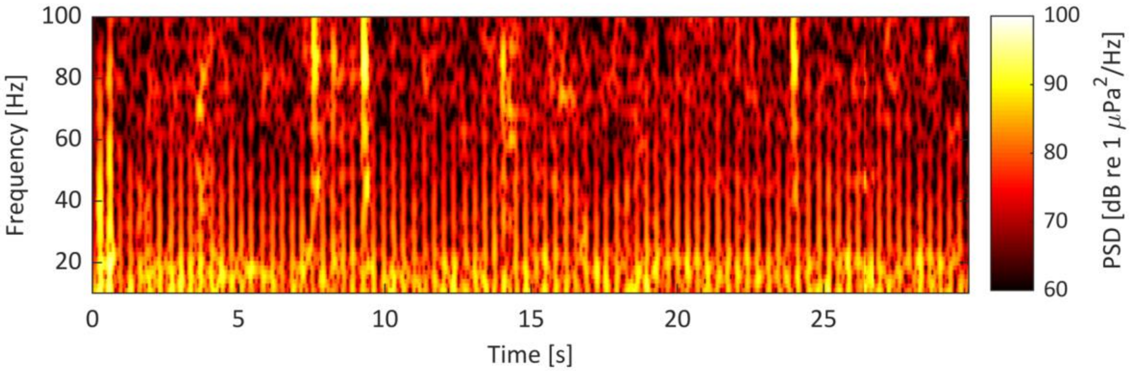


Figure 4 Example spectra containing low frequency persistent sound and 3 Hz pulse.

T_e = 8.5 s, H_{m0} = 0.8 m, January 17, 2019, 23:01 UTC.

3 DAISY Drifts

Drifting Acoustic Instrumentation SYstems (DAISYs) were used to investigate spatial trends in the soundscape and to rapidly identify sound originating from WECs and moorings. These systems were originally referred to as “Acoustic SWIFTs”, as the first hull design was adapted from SWIFT buoys used to measure wave fields. DAISY drifts are summarized graphically in Figure 5 and chronologically with associated survey reports in Table 2.

Figure 5 reflects patterns of intensity over time in surveys. Initial surveys focused on the Azura and, using early versions of the DAISYs, it was possible to survey in close proximity to the WEC, effectively “saturating” the area with DAISY drifts. Over time, it became apparent that this level of survey intensity was not required to provide useful information and, in conjunction with entanglement risks for newer versions of the DAISYs, led to sparser deployments. Berth occupancy is also reflected in the survey effort, which is focused primarily on the 30 m berth (where the most WECs have been tested), less activity at the 60 m (only occupied by Lifesaver), and sporadic surveys at the 80 m berth (no WEC testing to date).

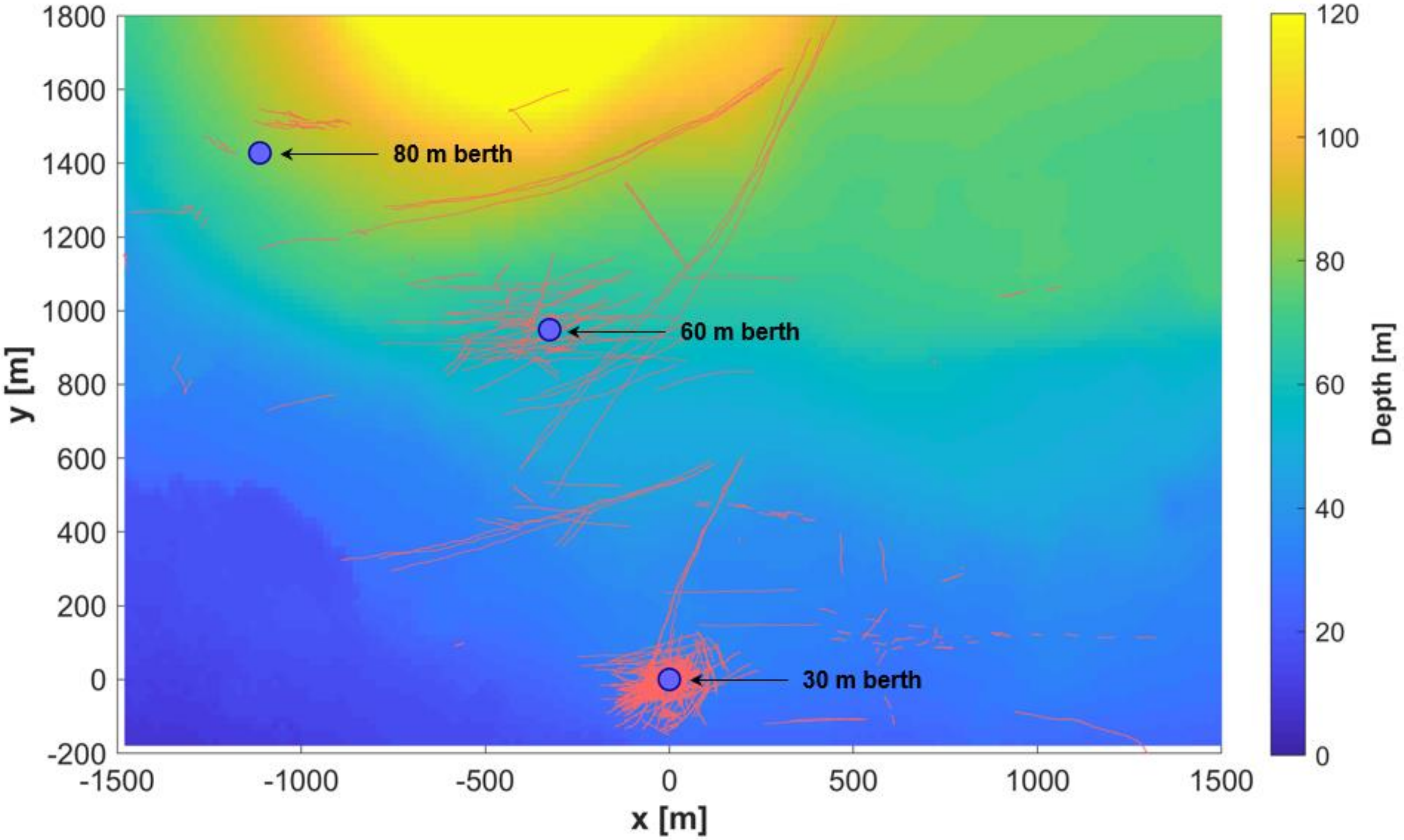
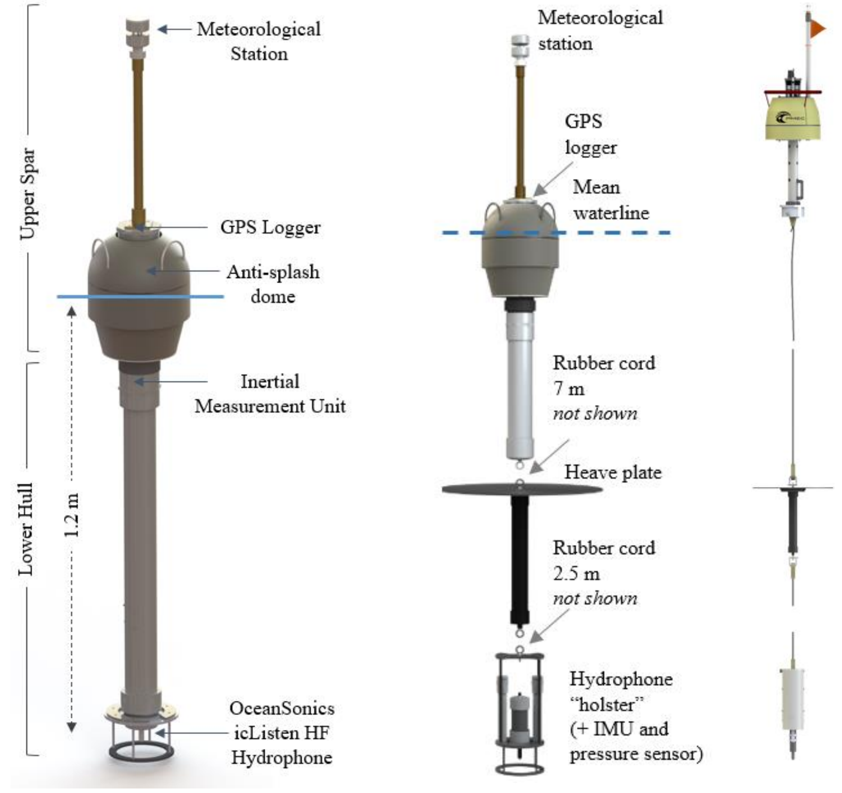


Figure 5: DAISY drifts at WETS (2015 – 2019)

Table 2: DAISY deployment summary and report references (2015 – 2019)

Survey Date	DAISY Version	Objectives	Report
March 2015	v1 – icListen and Loggerhead	Pre-installation observations Comparison of Loggerhead and icListen spar configurations	SWIFT Survey #1
July 2015	v1	Observations of Azura	SWIFT Survey #2
January 2016	v1	Observations of Azura	No report: low sea state
March 2016	v1	Observations of Azura Comparison between DAISY and Sea Spider Deployment vessel operations for Lifesaver	SWIFT Survey #3
August 2016	v1	Observations of Azura and Lifesaver Evaluation of DAISY flow shields	SWIFT Survey #4
December 2016	v1.5	Observations of Azura and Lifesaver Evaluation of prototype DAISY suspension systems	SWIFT Survey #5
January 2017	v1.5	Observations of Lifesaver (60 m berth) Observations at 30 m and 80 m berths Comparison between DAISY and Sea Spider	SWIFT Survey #6
March 2018	v1.5 lower / v2 upper	Observations of Azura 2.0 DAISY inter-comparison	DAISY Survey #1 (*DOD report*)
November 2018	v1.5 lower / v2 upper	Observations of Lifesaver (30 m berth) DAISY inter-comparison	SWIFT Survey #7
February 2019	v2	Observations of Lifesaver (30 m berth, no power generation) DAISY inter-comparison	SWIFT Survey #8

While the Sea Spider platform approach remained relatively static over the five year period (save for increased ballast), the DAISYs evolved considerably. The initial design (“v1”) consisted of an icListen HF (OceanSonics) hydrophone submerged approximately 1.2 m below the water surface and connected to a surface expression with a GPS via a rigid spar Figure 6a. During the first survey, an alternative that incorporated a Loggerhead DSG (predecessor to the DSG-ST used on the Sea Spider) was tested, but had poor handling characteristics due to the volume of the battery housing. The v1 DAISY was used extensively around the Azura deployment to map patterns in acoustic emissions. However, the rigid coupling to the surface expression introduced considerable flow-noise and self-noise (e.g., splashing) into the measurements, such that identification of sound at frequencies below a few hundred Hz was problematic. This motivated the development of a suspension system that could position the hydrophone deeper in the water and isolate it from surface expression motion Figure 6b (“v1.5”). This approach substantially reduced flow-noise and self-noise, allowing more accurate characterization of low-frequency acoustic emissions from the Azura and Lifesaver. A similar approach to reduce flow-noise in a moored logger (the “SLOW”) was not successful, but provided key insights into the development of the DAISY suspension system. The last evolution of the DAISY ("v2") involved integrating sensors providing ancillary information (e.g., GPS, motion) into a single system to facilitate deployment and offload by non-specialists. The v2 DAISY also replaced the icListen hydrophone with a custom integration of an HTI 99-UHF. The v2 DAISY is still a prototype instrument, with one more round of board revisions likely required to reduce high-frequency electrical noise that currently elevates the noise floor above 10 kHz.



(a) v1 DAISY **(b) v1.5 DAISY** **(c) v2 DAISY**

Figure 6: DAISY version evolution

As mentioned above, the v1 DAISYs produced significant self-noise and flow-noise, but had extremely high durability, such that they could be deployed at extremely close range to WECs without concern for instrumentation survival. The suspension system introduced in the v1.5 DAISY significantly reduced the amplitude of flow-noise and self-noise. This largely obviated the need to isolate contamination during analysis, but created a risk of entanglement with the WETS moorings and required more care to be taken during deployment (e.g., deploying DAISYs such that the dominant drift direction was away from potential entanglement). Overall, we feel that the benefits of the suspension system outweigh the costs.

Because of their limited temporal duration, drifts cannot readily resolve patterns arising from variations in sea state. They have, however, proven effective at identifying WEC and berth-attributable acoustic emissions when used in conjunction with a "reference site". Specifically, by comparing concurrent data from a DAISY in close proximity to a WEC and at considerable stand-off distance, it is possible to roughly estimate the acoustic contributions from the WEC and berth hardware (i.e., moorings). This does, however, require identifying a location within the same general area that has a similar ambient soundscape, but is beyond the range at which received levels from sources at the WEC and berth are detectable. Such a location was identified for the 30 m berth (approximately 1 km east), but similar approaches have been only partially successful at the 60 m and 80 m berths because the sound from their moorings is audible throughout the WETS survey area.

4 WETS Soundscape and WEC Contribution

The WETS soundscape is typified by three categories of sound:

- Wind and waves;
- Biological sound from humpback whales (seasonal) and snapping shrimp (diurnal); and
- Anthropogenic sound from the permanent moorings, particularly the 60 and 80 m berths.

Snapping shrimp produce a primarily diurnal variation in the soundscape, primarily at frequencies > 5 kHz, while humpback whale song is seasonal observed from 100 Hz to several kHz. During some seasons, the whale song is the dominant element of the soundscape, exceeding noise from the moorings.

The anthropogenic sound from the permanent moorings is relatively broadband, with primary emissions between 1 and 2 kHz, but extending to the upper limit of the DAISY hydrophones (200 kHz). Mooring noise is highest amplitude when they are not under tension, such that emissions from the 80 m berth were significantly higher amplitude than at the 60 m berth. During the Lifesaver deployment at the 60 m berth, one piece of mooring hardware was damaged, such that it produced a “warble” that dominated that soundscape for several months.

Observations of both Lifesaver deployments, as well as Azura and Azura 2.0 suggest that the primary emissions that can be attributable to a WEC are likely below a few kHz. This is shown, by way of example Figure 7, for the Lifesaver deployment at the 30 m berth. First, note that received levels during power generation definitively exceed those at the reference location from approximately 20 Hz to 20 kHz (reference levels in Nov. 2018 were similar to Feb. 2019). Second, note that sound in close proximity to the Lifesaver continues to marginally exceed the reference spectrum, even when it is not in operation. However, without the ability to localize sound, it is difficult to know if this sound is originating from the moorings at the 30 m berth or from the Lifesaver hull. Either way, this sound shows little directional dependence (similar received levels 25 m to the east and south), but would likely be barely detectable above ambient levels at a range of 100 m. This highlights the complementarity of the Sea Spider and DAISY surveys: using DAISYs deployed at close range, we can identify frequencies of importance for Sea Spider monitoring. Finally, while there is divergence between the power generation and idle states at frequencies < 20 Hz, it is difficult to establish, with confidence if this is a variation in flow-noise/self-noise with sea state or propagating sound.

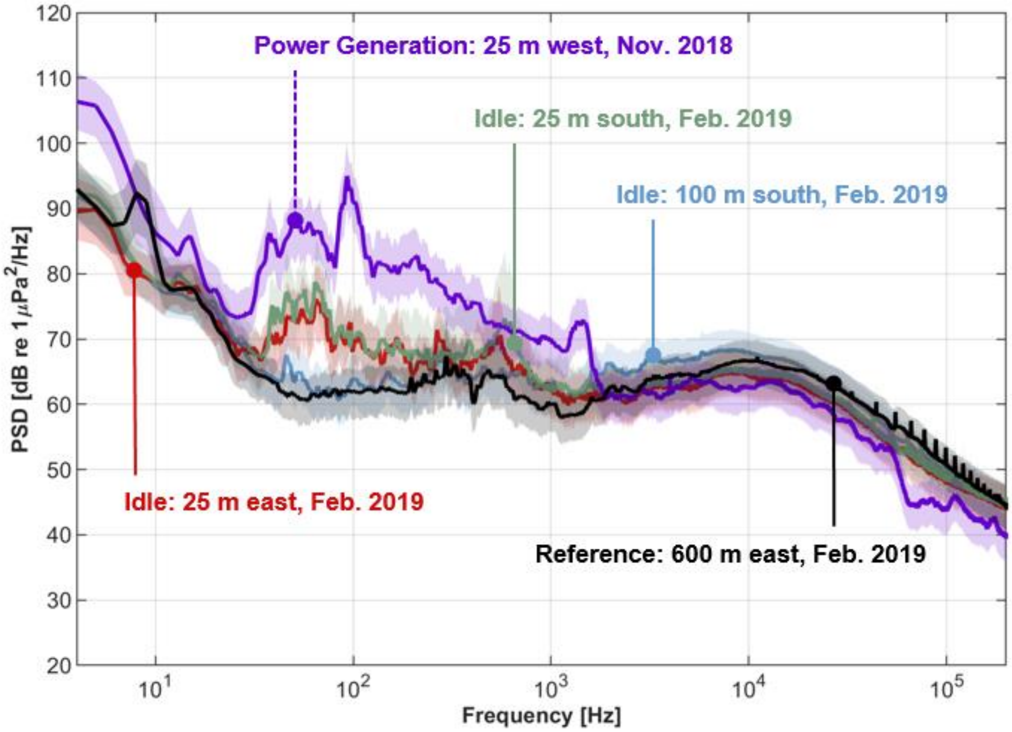


Figure 7: Acoustic emissions associated with Lifesaver testing at 30 m berth

5 Impact

In 2015, at the start of the surveys, only a handful of acoustic measurements had been made of WECs anywhere in the world and there was no consensus on the consequences of their acoustic emissions. Further, no standardized approaches existed to improve this understanding in a transparent and transferable manner. Over the past five years, a growing evidence base suggests that acoustic emissions from WECs are unlikely to cause physical harm to marine mammals. This same evidence base suggests that acoustic emissions can be audible to most marine mammals and, consequently, has the potential to cause changes to their behavior.

The acoustic data collected at WETS has contributed to this evidence base, which, in aggregate, should help to reduce barriers to future deployments. Of potentially greater significance is the contribution of these measurements to the first international consensus specification for acoustic measurements of marine energy converters under the auspices of the International Electrotechnical Commission (IEC) 62600-40. These surveys served as a test bed for approaches under consideration by the IEC project team, helping to refine the technical specification and choose approaches that could be effective under real-world conditions.

6 Next Steps

IEC 62600-40 acknowledges two main areas of uncertainty in acoustic measurements at wave energy sites.

The first is an inability to attribute acoustic emissions to a wave energy converter to a specific element of the converter. At WETS, for example, a persistent sound that appeared during the deployment of the Lifesaver at the 60 m berth was attributed to a damaged PTO bearing by the project team, including

Fred. Olsen engineers, on the basis of DAISY data. Subsequent analysis of long-term fixed measurements overturned this conclusion, showing that the sound returned after Lifesaver was removed and attributing the source to a damaged component of the permanent mooring at the berth. Similarly, wide-band acoustic emissions from around the Lifesaver were initially misidentified as bubble collapse from breaking waves on the hull before a strict protocol for conducting concurrent reference surveys was established. This challenge in attribution could be resolved by acoustic localization, either through time-delay-of-arrival array processing or vector sensing of acoustic particle velocity. Both techniques are under development and, fittingly, will be tested at WETS in the relatively near future.

The second is masking by flow-noise at relatively low frequencies (< 100 Hz). This is produced when relative velocity differences exist between the hydrophone and surrounding water. These differences cause eddies to be shed by the hydrophone, which have associated pressure fluctuations that are relatively high-amplitude compared to propagating sound. A similar phenomenon occurs when turbulent motion interacts with the hydrophone. Drifting hydrophones with suspension systems are able to minimize, but not eliminate, flow-noise. However, no such approach has been demonstrated for fixed instrumentation, nor is there yet consensus on a methodology to objectively differentiate between flow-noise and other low-frequency sounds in acoustic measurements, particularly as frequencies approach the lower limits of marine mammal hearing (~10 Hz). Equipment purchases planned for WETS include multichannel acoustic recorders and flow-shields that may be effective at suppressing flow-noise and/or reducing its amplitude in recordings.

IEC 62600-40 establishes two levels of acoustic measurements: Level A and Level B. The Level B measurement consists of a temporal snapshot of WEC sound at a point in space and can be obtained either using drifting or fixed hydrophones. The Level A measurement consists of multiple such snapshots to build an understanding of how WEC-attributed sound varies with sea state, but must be acquired with fixed hydrophones. This is comparable to the fixed measurement approach employed at WETS for the past five years. However, the Level A measurement requires two fixed platforms deployed orthogonally to the dominant wave direction around the WEC. WETS currently has only a single fixed platform, but is in the process of procuring a second, such that conformity with Level A characterization should be feasible in the relatively near future.

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