Acoustic Characterization around the CalWave Wave Energy Converter

Kaustubha Raghukumar, Katherine Heal, Grace Chang, Frank Spada

Abstract— **Sound generated by marine energy (ME) installations in the ocean remains a particular concern for environmental permitting despite the limited evidence showing low levels of ME sounds relative to other anthropogenic sounds. To increase understanding of potential environmental effects of marine energy projects and help reduce barriers to marine energy deployments, a new directional acoustic monitoring technology, the NoiseSpotter®, was developed and recently demonstrated around CalWave's operational xWave™ wave energy converter (WEC) pilot.**

Results are presented from co-deployments of NoiseSpotter® with the operational CalWave WEC that were conducted over a 9-day period in fall 2021 offshore of Scripps Research Pier in San Diego, California, U.S.A.

Sound levels from the WEC reveal little deviation from the ambient soundscape. The azimuthal anisotropy of WEC sound was investigated via deployments along four cardinal directions around the WEC. While a noticeable increase was observed along the north-south orientation, the sound levels along all directions still showed little deviation relative to the ambient noise floor. Analysis of low-level WEC sounds demonstrate the utility of directional acoustic sensing in distinguishing marine energy sounds from the myriad other sounds in the surrounding ocean environment.

Keywords—**resource characterization, internal waves, surface waves**

I. INTRODUCTION

Observing and understanding the complexity of marine soundscapes [1] and the organisms that contribute to and navigate within, is of growing importance to regulators and resource managers tasked with marine spatial planning. Good stewardship requires overseeing protected areas and siting of marine energy projects such that energy yields are maximized, while environmental impacts are minimized [2–5]. Marine energy technologies are at an early stage of development because of the fundamental challenges of generating power from dynamic waves and currents, while surviving in corrosive marine environments. These challenges are intensified by high costs and lengthy processes (up to 10 years) associated with permitting. Of the many environmental effects that are of concern, the effect of radiated sound on the marine environment has gained considerable attention.

Many industrial activities associated with marine energy installation, operation, and decommissioning generate anthropogenic sounds that overlap spatially, temporally, and in bandwidths pertinent to biological signals important to marine fauna [6]. Observed changes in vocalization behaviour (e.g. the Lombard effect, masking release strategies) would indicate disturbance to marine species from new or significant changes in anthropogenic activities near critical habitat space, such as vessel traffic, offshore construction, and marine energy devices. Monitoring and quantifying these disturbances and the correlated vocal reactions by marine fauna will create informed mitigation efforts of regulatory and stakeholder relevance. Further, studies on the potential acoustic effects of anthropogenic sounds on marine animals do not yet consider the full range of potential effects, particularly those related to particle motion, the acoustic field of particular relevance to fishes and invertebrates [7].

Here, we report on recent measurements of the acoustic environment around the CalWave wave energy converter (WEC) that was deployed offshore of the Scripps Research Pier in San Diego, California, U.S.A from September 2021 to July 2022. During this deployment, a new directionally acoustic sensing technology, the NoiseSpotter®[8] was deployed at various locations around the WEC over a period of 10 days in November 2021. During this period, the acoustic environment consisted of mooring sounds from the WEC, small boat traffic, a hovering helicopter and marine mammal vocalizations. It is shown in this paper that the ability to directionally discriminate acoustic

"This work was supported in part by the Water Power Technologies office of the U.S. Department of Energy"

Kaustubha Raghukumar, Katherine Heal, Grace Chang and Frank Spada are at Integral Consulting Inc, 200 Washington Street, Suite 201, Santa Cruz, California, 95060, U.S.A (e-mails: kraghukumar@integral-corp.com, kheal@integral-corp.com, gchang@integral-corp.com, fspada@integral-corp.com,).

Digital Object Identifier: https://doi.org/10.36688/ewtec-2023-187

sounds is important in correctly attributing sounds in the marine environment to the WEC.

II. Background

From September 2021 to July 2022, CalWave's operational xWave™ WEC pilot was deployed offshore of the Scripps Research Pier in San Diego, California, U.S.A (Fig. 1). This deployment represented the longest continuous deployment of an operational WEC to date, and provided a unique opportunity to examine the underwater acoustic environment around the device.

Fig. 1. CalWave XWave™ WEC as deployed in San Diego, California.

Acoustic measurements during a portion of the CalWave deployment were conducted using the NoiseSpotter®, a new directional acoustic sensing technology [8]. NoiseSpotter® has been developed to support the evaluation of potential acoustic effects of marine and hydrokinetic (MHK) energy devices. MHK devices are expected to emit low intensity sounds on the order of 110–130 decibels (dB) referenced to 1 microPascal (re uPA) at 1 m [9]. Therefore, in order to characterize MHK sounds, it is important to be able to distinguish it from other sources of sound such as boats, marine mammals and fish choruses.

NoiseSpotter® seeks to improve upon traditional acoustic sensing techniques through integration of a compact array of acoustic vector sensors with custom data dissemination technologies to characterize, classify, and provide accurate location information, in near real-time, for anthropogenic and natural sounds.

Traditional acoustic sensing techniques typically involve the use of hydrophones that measure scalar acoustic pressure. Consequently, directional discrimination requires the use of large arrays consisting of multiple hydrophones [10]. Instead, the NoiseSpotter® consists of three acoustic vector sensors (Fig. 2), each of which measures three-dimensional acoustic particle velocity in addition to acoustic pressure, in the frequency range 50 Hz to 3 kHz. The vector measurement inherently provides directional information (acoustic bearing) to a source of sound. A vector sensor array can therefore triangulate individual measured bearings to provide sound source localization, and thereby help characterize sound specific to a source, such as a WEC.

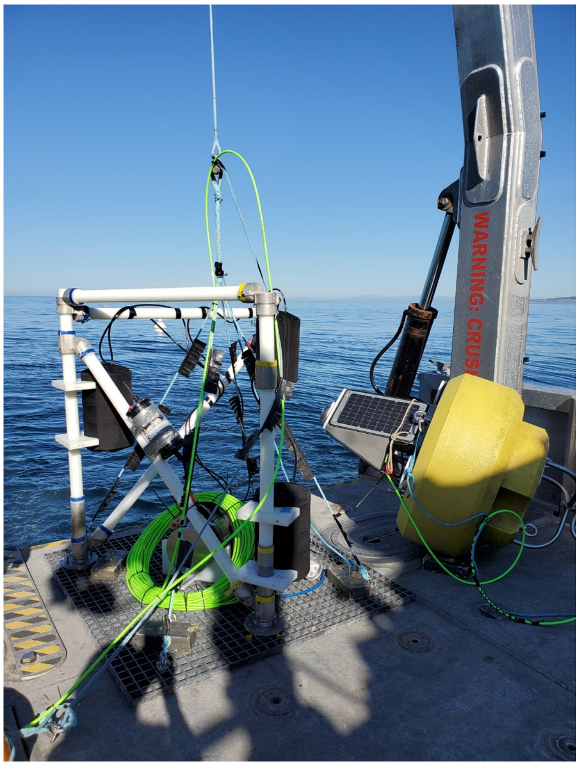

Fig. 2. The NoiseSpotter® consisting of three vector sensors housed inside the black cylindrical pods, along with surface telemetry buoy.

III. Methodology

The NoiseSpotter® was deployed offshore of the Scripps Institution of Oceanography (SIO) Pier, San Diego, California in November 2021. The specific goal of this deployment was to demonstrate NoiseSpotter performance near an operational WEC. As part of this demonstration, the NoiseSpotter was deployed in ~30 m deep water during multiple deployments over an approximate 10-day period. The demonstrations consisted of:

1. A drifting configuration of the NoiseSpotter.
2. Deployments of the NoiseSpotter® over periods of 4-6 hours, approximately 70 m from the CalWave WEC to demonstrate near real-time telemetry.
3. Shorter-term deployments of the NoiseSpotter® approximately 100 m and 200 m from the CalWave device at the four cardinal directions from the WEC.
4. A multi-day autonomous deployment of the NoiseSpotter® to demonstrate longer-term acoustic monitoring ability.

During the deployments, the NoiseSpotter monitored for operational sounds from the CalWave device, boat traffic, and marine mammals in the frequency band 50 Hz to 3 kHz. Presented below are results from the deployments at the four cardinal directions and the multi-day autonomous deployment.

IV. Results

Operational sounds from the WEC were characterized at two distances (100 m and 200 m) from the CalWave device, at four cardinal directions (north, south, east and west of WEC) over the course of two field days (November 17-18, 2021). This effort represents a comprehensive characterization of WEC sounds as a function of distance, along with a characterization of the anisotropy of WEC sounds to aid in future three-dimensional acoustic propagation modelling. This characterization effort was conducted in collaboration with CalWave, who changed various device operational parameter as part of the testing during the NoiseSpotter demonstration deployments.

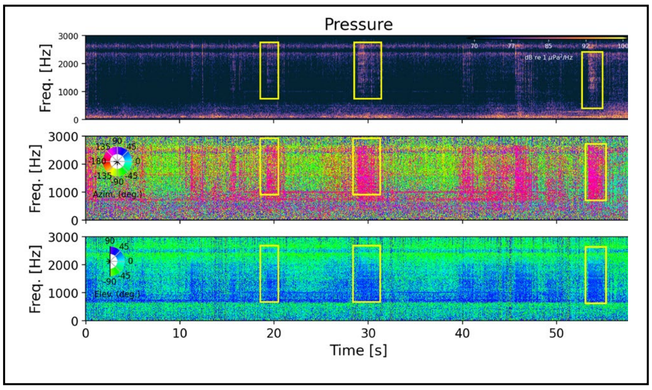

Fig. 3. 'Azigram' of measured WEC sounds showing spectrogram of acoustic pressure (top panel), azimuthal angle (middle panel) and elevation angle (lowest panel) for a 1-minute segment of data. WEC sounds are identified as those arriving from the 60-90° azimuthal bin. The yellow boxes show identified WEC sounds based on the azimuthal angle (middle panel) to the known WEC location.

A variety of sounds were measured around the CalWave WEC that included sounds from a hovering helicopter, small boats and the opening/closing of the hatch on the WEC. Directional processing was applied to pressure and particle motion data following the methods described by Ref. 11. These directional processing algorithms provide an 'azigram' (Fig. 3) for each minute of data, which shows the conventional spectrogram in addition to the frequency- and time-dependent azimuthal and elevation angles. Azimuth and elevation angles obtained from the particle motion sensor data are corrected using digital compass data such that the bearings displayed in the azigrams are in true earth coordinates, i.e. 0°, 90°, 180° and -90° indicate true north, east, south and west respectively. The colors in the middle and lowest panels indicate an angle associated with each frequency, at each time. During this time, the NoiseSpotter® is located due west of the WEC (i.e. the WEC has bearing of 90° with 0° being true north). Therefore, WEC sounds are directionally identified as those colors associated with the 90° azimuth in the azigram.

During periods that are considered potential WEC sounds, such as the pulses near 20 s and 30 s, there is a clear directional signal associated with the 90° azimuth (middle panel, Fig. 3). Similarly, the elevation angle associated with the WEC sounds is between 15-20°, close to the true elevation angle of 14° in 25 m water depth, at a distance of 100 m from the WEC. The sound pulses attributed to the WEC were broadband, and spanned the frequency range 200-2700 Hz. As seen in Fig. 3, directional processing can help identify specific signals of interest from other potentially confounding signals.

The multiple deployments at four cardinal directions around the WEC allowed for a characterization of the spatial anisotropy of sound from the WEC. Fig. 4 shows spectra of pressure and particle motion using 20 minutes of data gathered along each cardinal direction, at a distance of 100 m from the WEC.

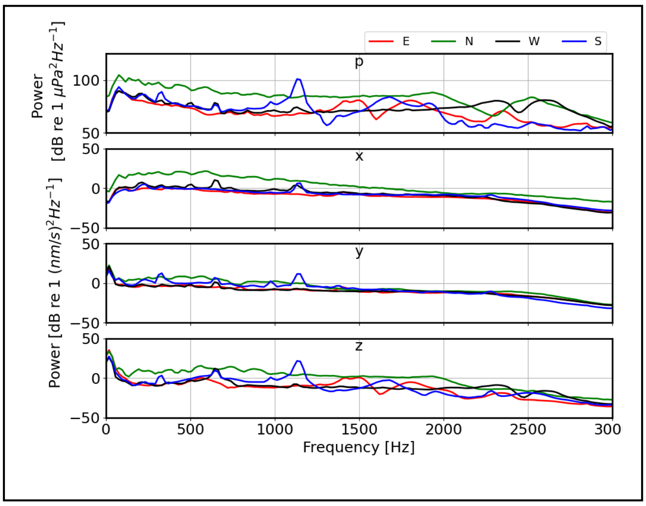

Fig. 4. Spectra of pressure (p) and each particle motion channel (x,y,z) at each of the four cardinal directions (West, North, East, South).

Strong anisotropy is observed, with the anisotropy likely being related both to temporal variability in WEC sounds/ambient noise and propagation-related anisotropy of WEC sounds. The elevated noise levels north of the WEC are likely due to temporary increases in local ambient noise levels, while the spectral peaks at 200 Hz, 300 Hz, 600 Hz and 1200 Hz are likely WEC sounds that do indeed exhibit strong anisotropy, with the largest amplitude peaks occurring 100 m south of the WEC.

Fig. 5 shows azimuthal anisotropy of sound pressure levels over the entire sensor bandwidth (50 Hz to 3 kHz), and sub-bands 0-500 Hz, 500-1000 Hz and 1-3 kHz. When integrated over the entire bandwidth, sound pressure levels are largest north of the WEC, and the north-south variability is most pronounced in the 0-500 Hz frequency band. Sound pressure levels in the 500-1000 Hz band are almost identical to the west and east, and elevated to the south and north. In the 1-3 kHz band, sound pressure levels are lowest to the east, identical to the west and south, and highest to the north. Finally, in the 1-3 kHz band, sound pressure levels are identical to the west and east, and higher, but almost identical to the north and south.

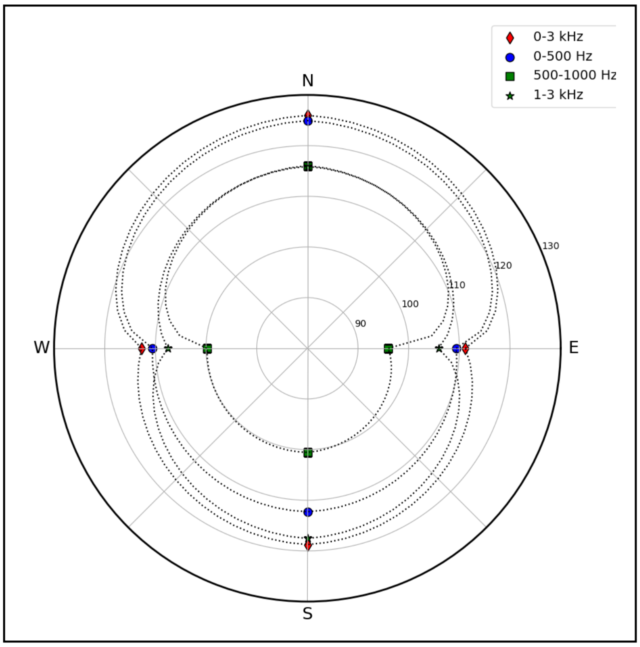

Fig 5. Azimuthal anisotropy of sound pressure levels across different frequency bands.

Sound exposure levels associated with various sounds measured during the deployment are listed in Table 1. All the sounds listed in Table 1 overlapped in frequency range, highlighting the utility of directional discrimination in isolating the various sounds. The sound exposure level is computed as the average power over a 60 second window, and is a useful metric to compare chronic exposure of animals to continuous sounds. Other metrics such as peak sound pressure levels compare peak levels associated with more impulsive sounds, and can show greater differences between various sounds, but are somewhat less useful in terms of effects on marine mammals. The table of SELs shows that the anthropogenic sounds associated with the WEC are comparable to those from marine mammals, and 8 dB lower than those from a boat.

TABLE I
SOUND EXPOSURE LEVELS COMPUTED OVER MINUTE-LONG DATA SEGMENTS FOR VARIOUS SOUNDS MEASURED DURING THE DEPLOYMENT.

Source	$LE_{,60s}$ (dB re 1 μPa^{2}s)	Frequency
WEC	139	200-2700 Hz
Boat	147	50-3000 Hz
Helicopter	140	200-1000 Hz
Gray Whale	138	100-2000 Hz

V. CONCLUSION

The multi-day deployment of the NoiseSpotter® at 100 m and 200 m from the CalWave xWave™ WEC revealed a rich library of sounds that include:

- Low-level (~95 dB re 1 μPa relative to an ambient noise floor between 80-90 dB re 1 μPa) sounds from the WEC associated with the deliberate actuation of mechanical components,
- Sounds from a hovering helicopter,
- Marine mammal vocalizations, and,
- Small boat engines.

Directional processing helped isolate WEC sounds from the surrounding environment, and compute sound exposure levels for the WEC sounds compared to other sounds in the acoustic environment. Sound exposure levels at a distance of 100 m from the WEC were found to be lower than those from nearby boats, a hovering helicopter approximately 1 km away, and comparable to those from a gray whale at an unknown distance from the WEC. These low levels of WEC sound measured by the NoiseSpotter® can help allay concerns about radiated noise from the CalWave WEC.

REFERENCES

[1] S. Haver et al., "Monitoring long-term soundscape trends in U.S. waters: The NOAA/NPS Ocean Noise Reference Station Network," *Mar. Policy*, vol. 90, pp. 6–13. 2018. doi: 10.1016/j.marpol.2018.01.023

[2] H. Jeffrey, J. Brighid, and M. Winskel, "Accelerating the development of marine energy: Exploring the prospects, benefits and challenges," *Technological Forecasting and Social Change*, vol. 80, pp. 1306-1316, 2013. https://doi.org/10.1016/j.techfore.2012.03.004

[3] G. Wright, "Marine governance in an industrialised ocean: A case study of the emerging marine renewable energy industry," *Marine Policy*, vol. 52, pp. 77-84, 2015. https://doi.org/10.1016/j.marpol.2014.10.021

[4] R. Roche, et al., "Research priorities for assessing potential impacts of emerging marine renewable energy technologies: Insights from developments in Wales (UK)," *Renewable Energy*, vol. 99, pp. 1327-1341, 2016. https://doi.org/10.1016/j.renene.2016.08.035

[5] A. Copping and L. Hemery, editors. "OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World," *Report for Ocean Energy Systems (OES)*, 2020. doi:10.2172/1632878

[6] FHWG (Fisheries Hydroacoustic Working Group), "Memorandum, agreement in principle for guidelines for injury to fish from pile driving activities," *NOAA Fisheries Northwest and Southwest Regions, US Fish and Wildlife Service Regions 1 and 8, California/Washington/Oregon Departments of Transportation, California Department of Fish and Game, and U.S. Federal Highway Administration*, 2008.

[7] A. Popper and A. Hawkins, "The importance of particle motion to fishes and invertebrates," *J. Acoust. Soc. Amer.*, vol. 143, pp. 470–488., 2018.

[8] K. Raghukumar, G. Chang, F. Spada, and C. Jones, "A vector sensor-based acoustic characterization system for marine renewable energy," *J. Mar. Sci. Eng.*, vol. 8, pp. 187, 2020. doi:10.3390/jmse8030187.

[9] J. Tougaard, "Underwater noise from a wave energy converter is unlikely to affect marine mammals," *PLoS ONE*, vol. 10, 2015.

[10] A. Thode, J. Skinner, P. Scott, J. Roswell, J. Straley, and K. Folkert. "Tracking sperm whales with a towed acoustic vector sensor," *J. Acoust. Soc. Amer.*, vol. 128, pp.2681-2694, 2015.

[11] A. Thode, T. Sakai, J. Michalec, S. Rankin, M. Soldevilla, B. Martin, and K. Kim, "Displaying bioacoustic directional information from sonobuoys using "azigrams"", *J. Acoust. Soc. Amer.*, vol. 146, pp.95-102, 2019.